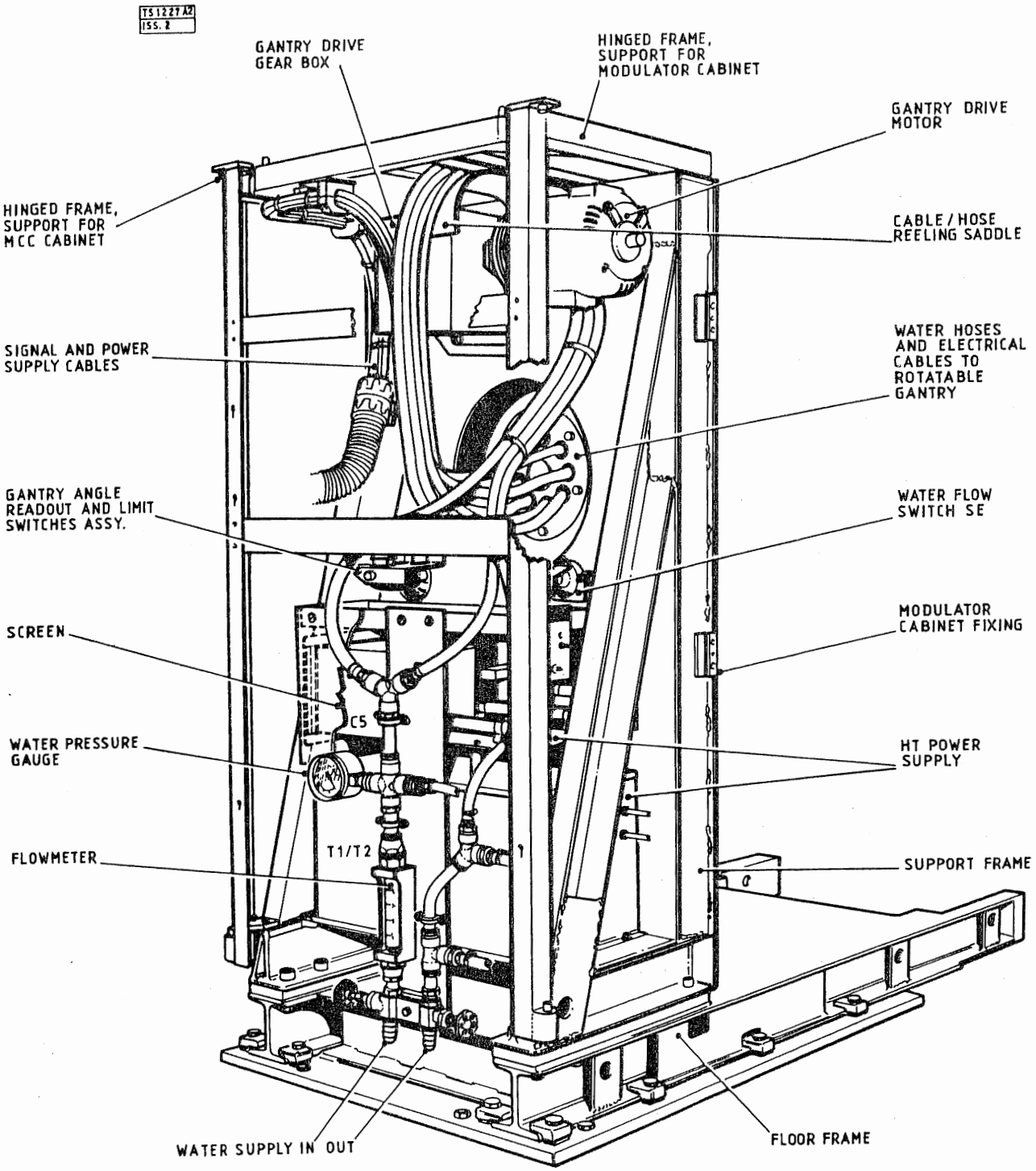

Figure 1: Gantry Support Frame Assembly

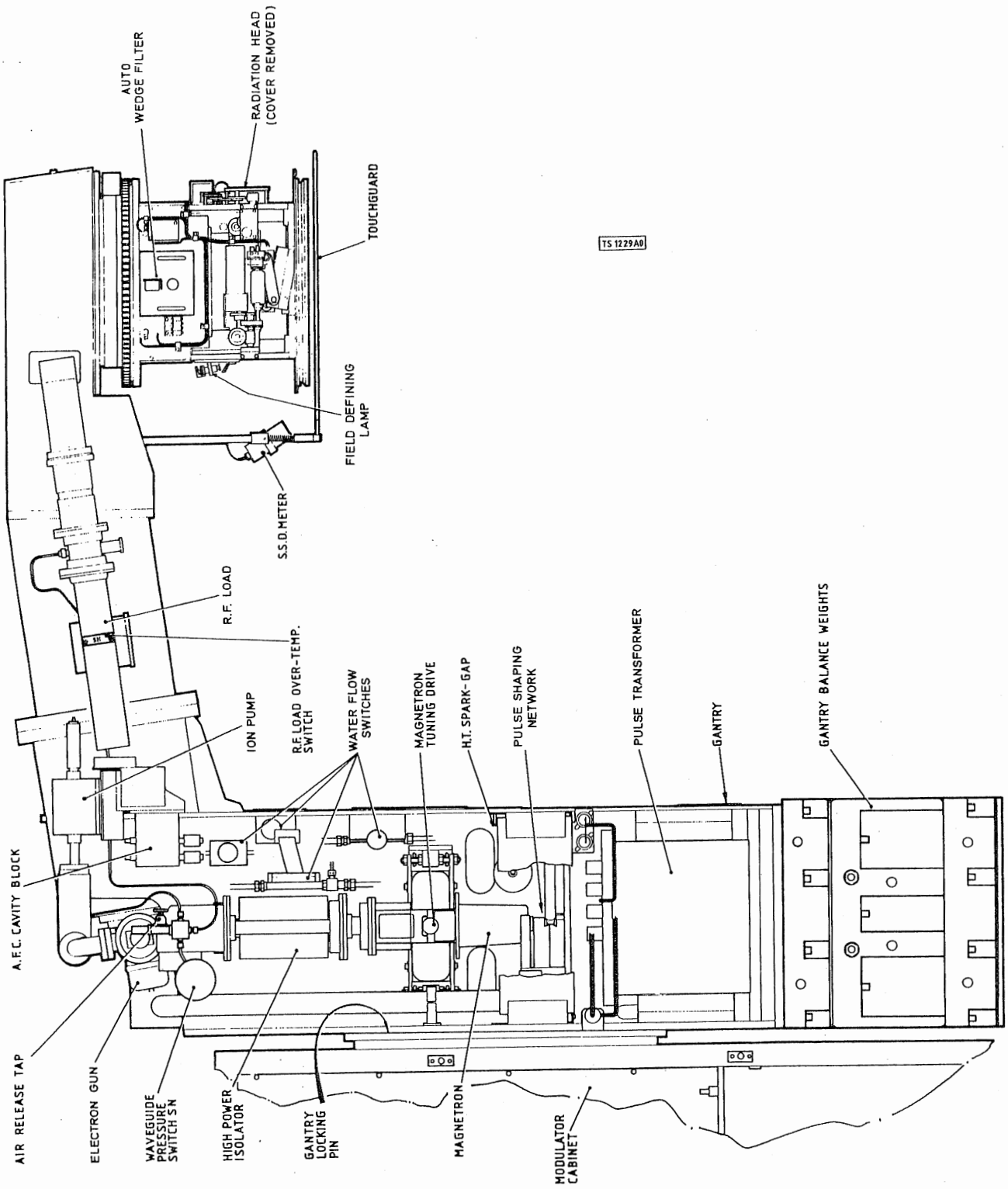

Figure 2: Gantry, left-hand side

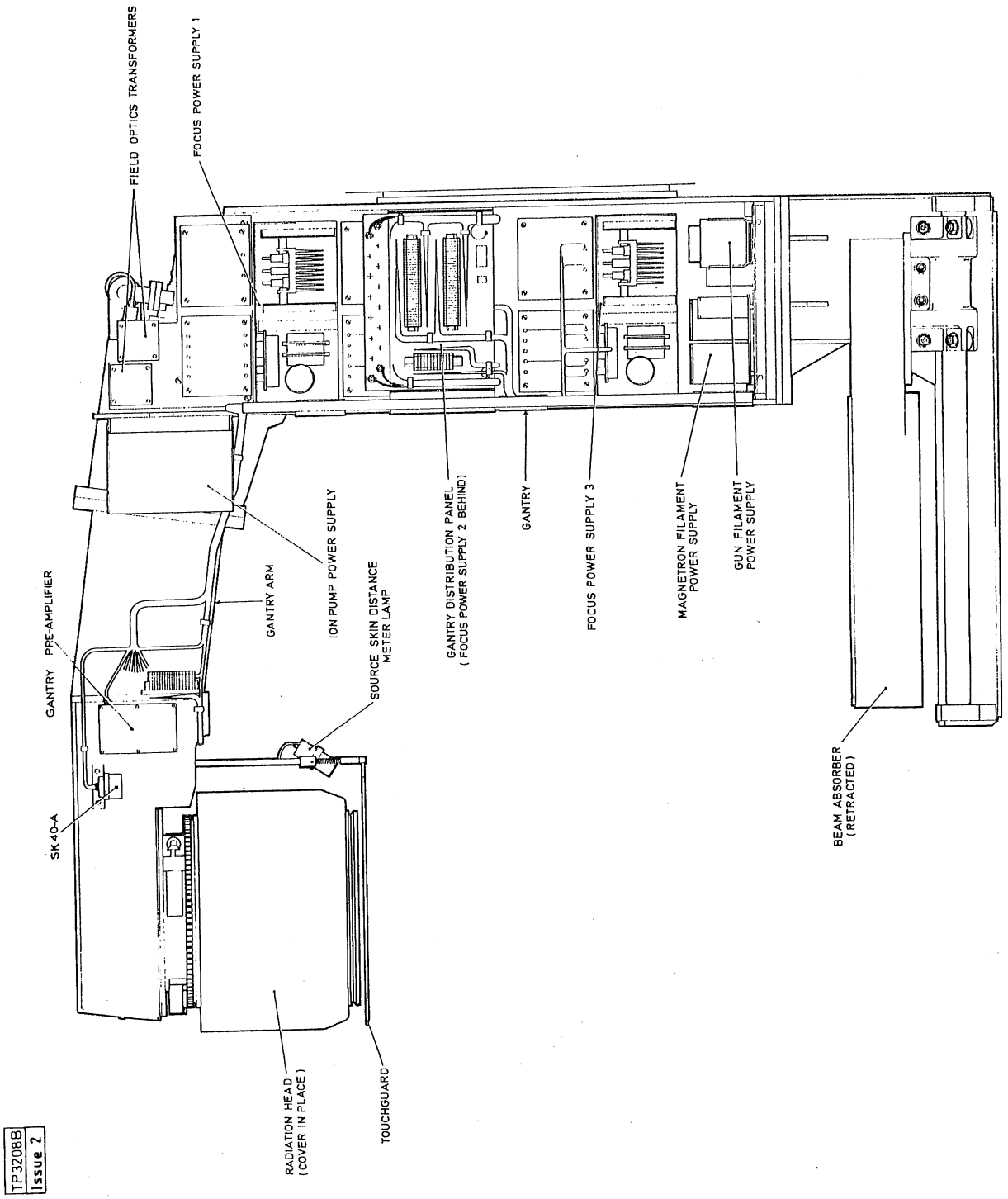

Figure 3: Gantry, right-hand side showing optional beam absorber

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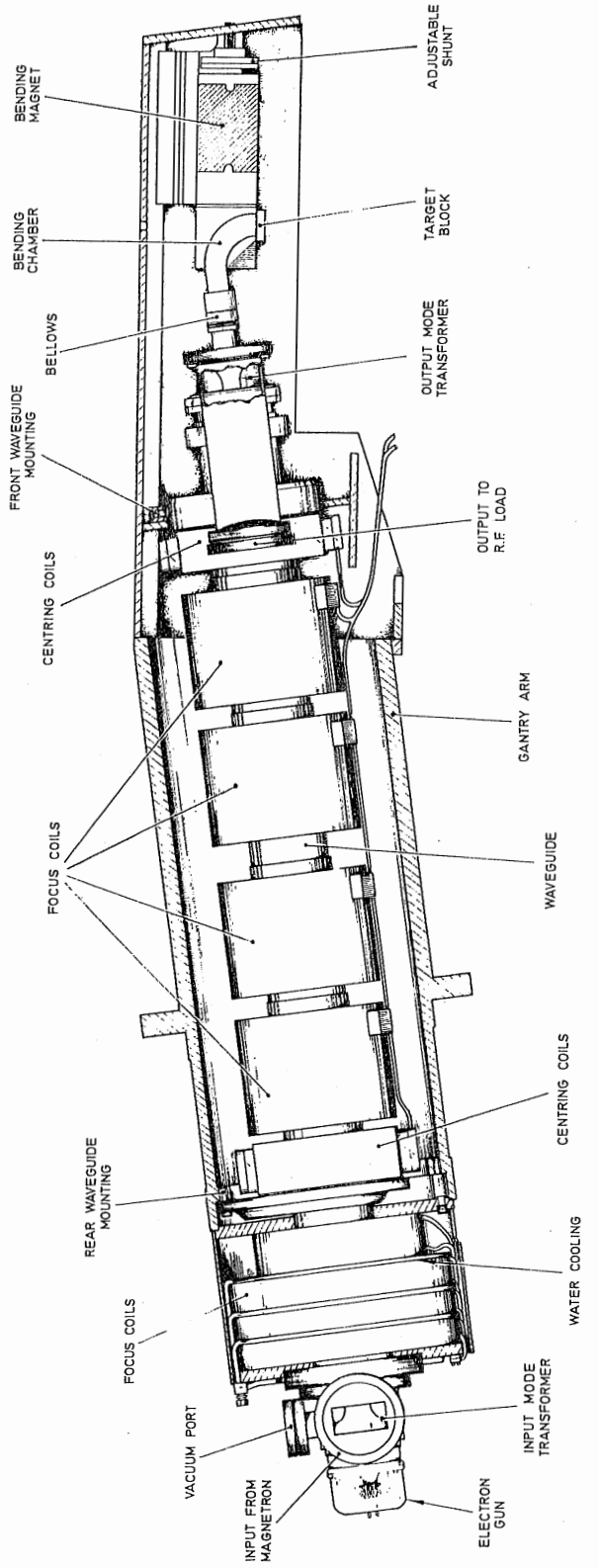


Figure 4: Gantry Arm

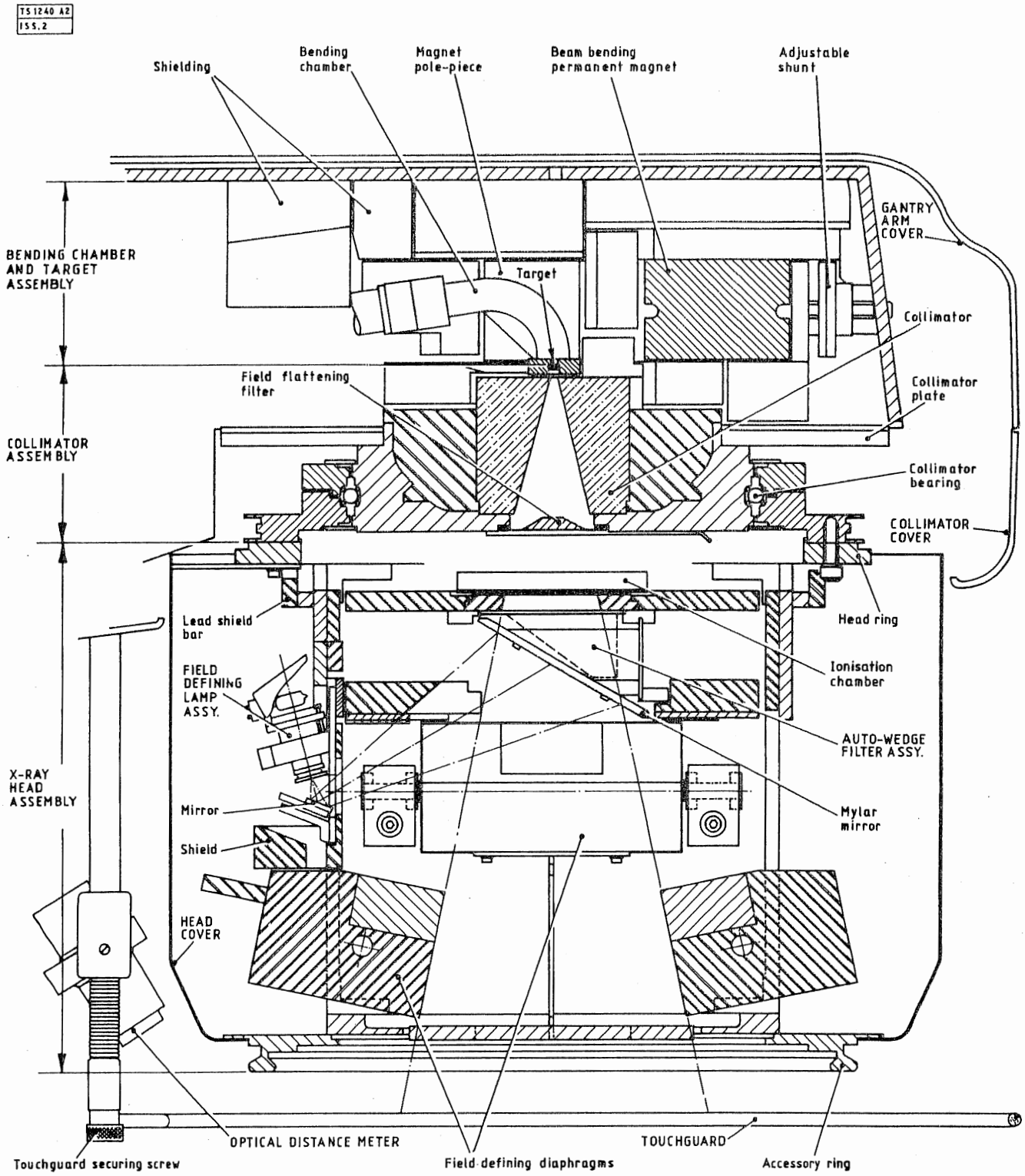


Figure 5: Radiation Head Assembly for SL75-5

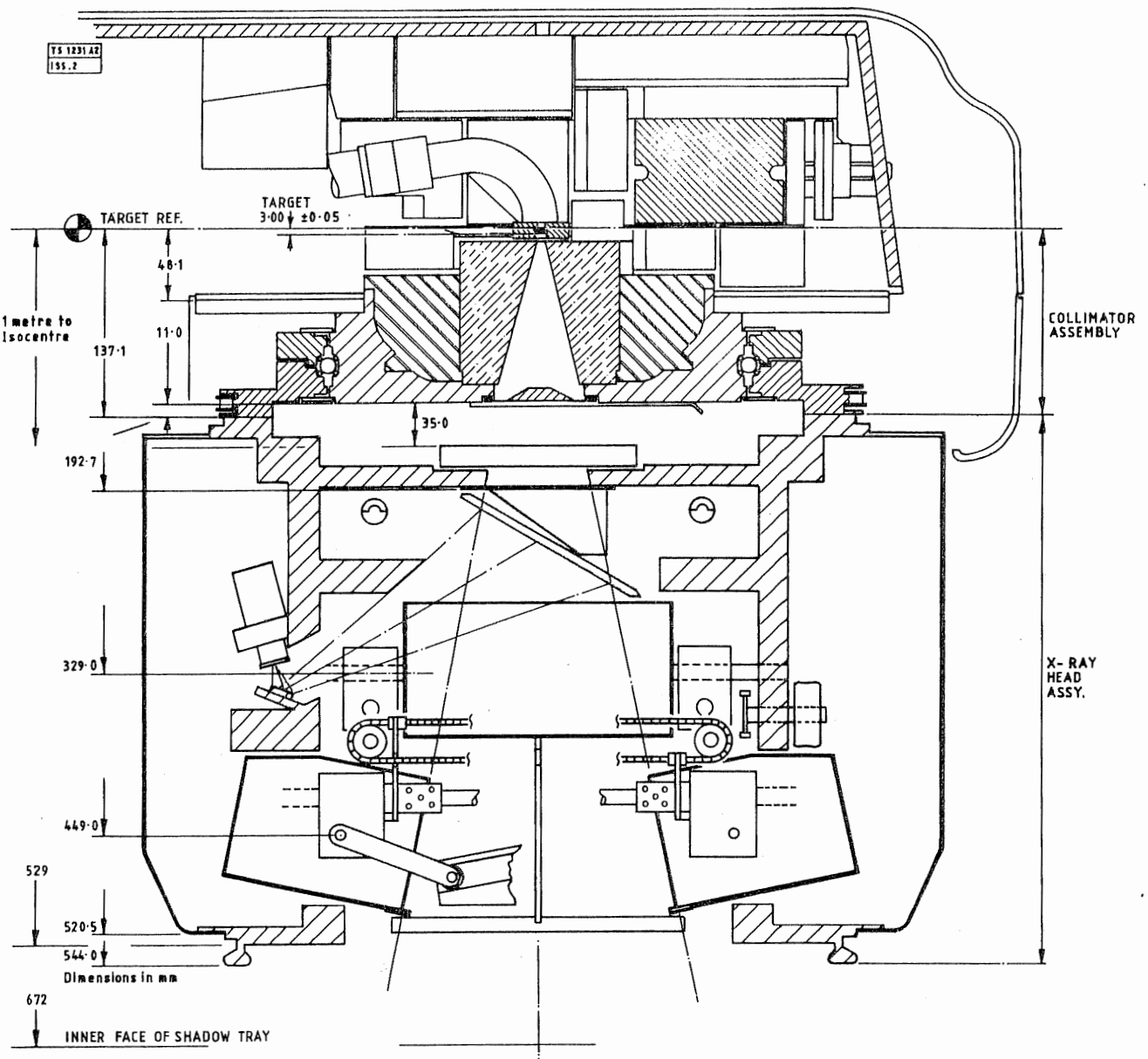


Figure 6: Radiation Head, sectional view with reference dimensions

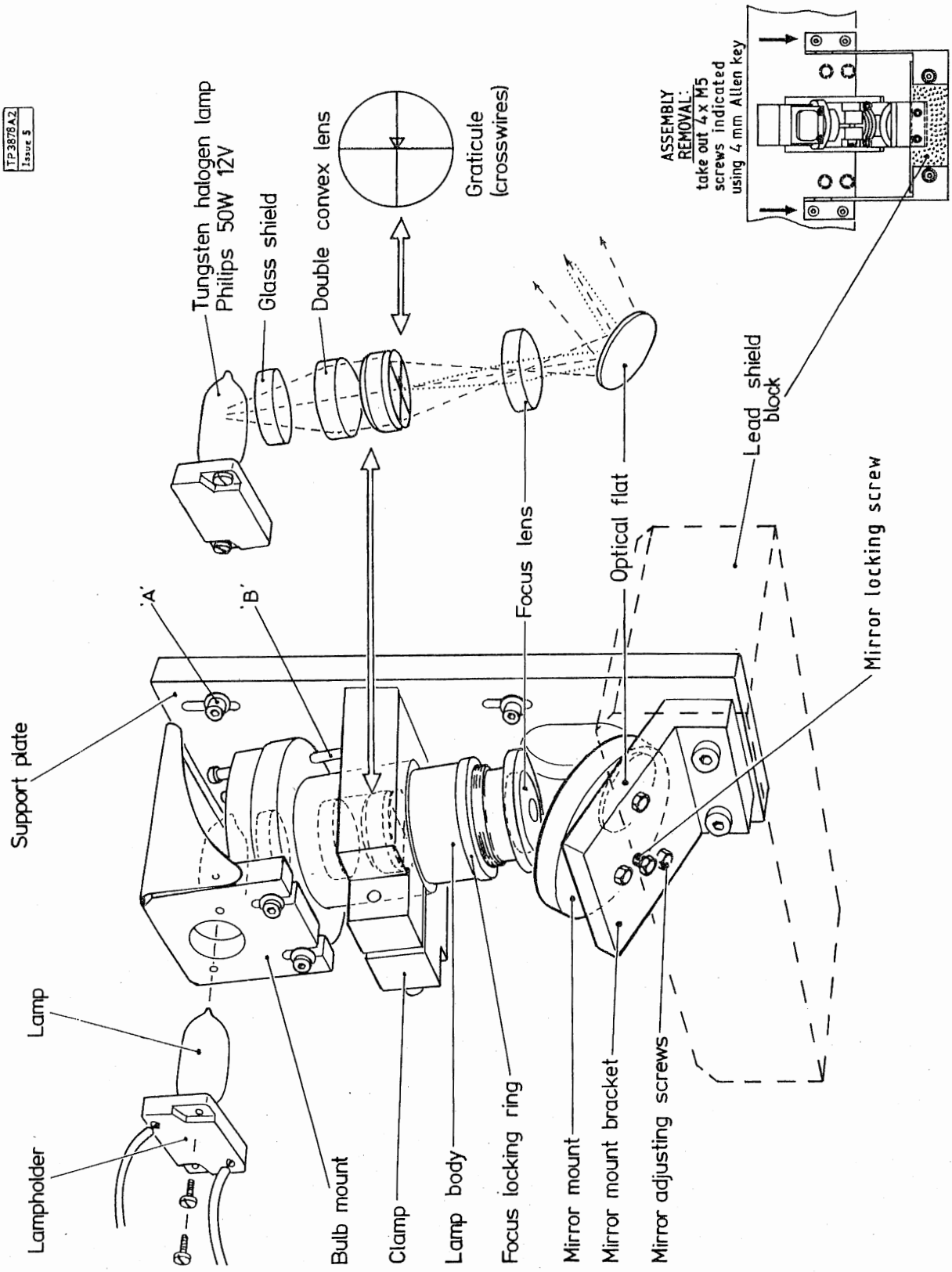


Figure 7: Field-Defining Lamp Assembly

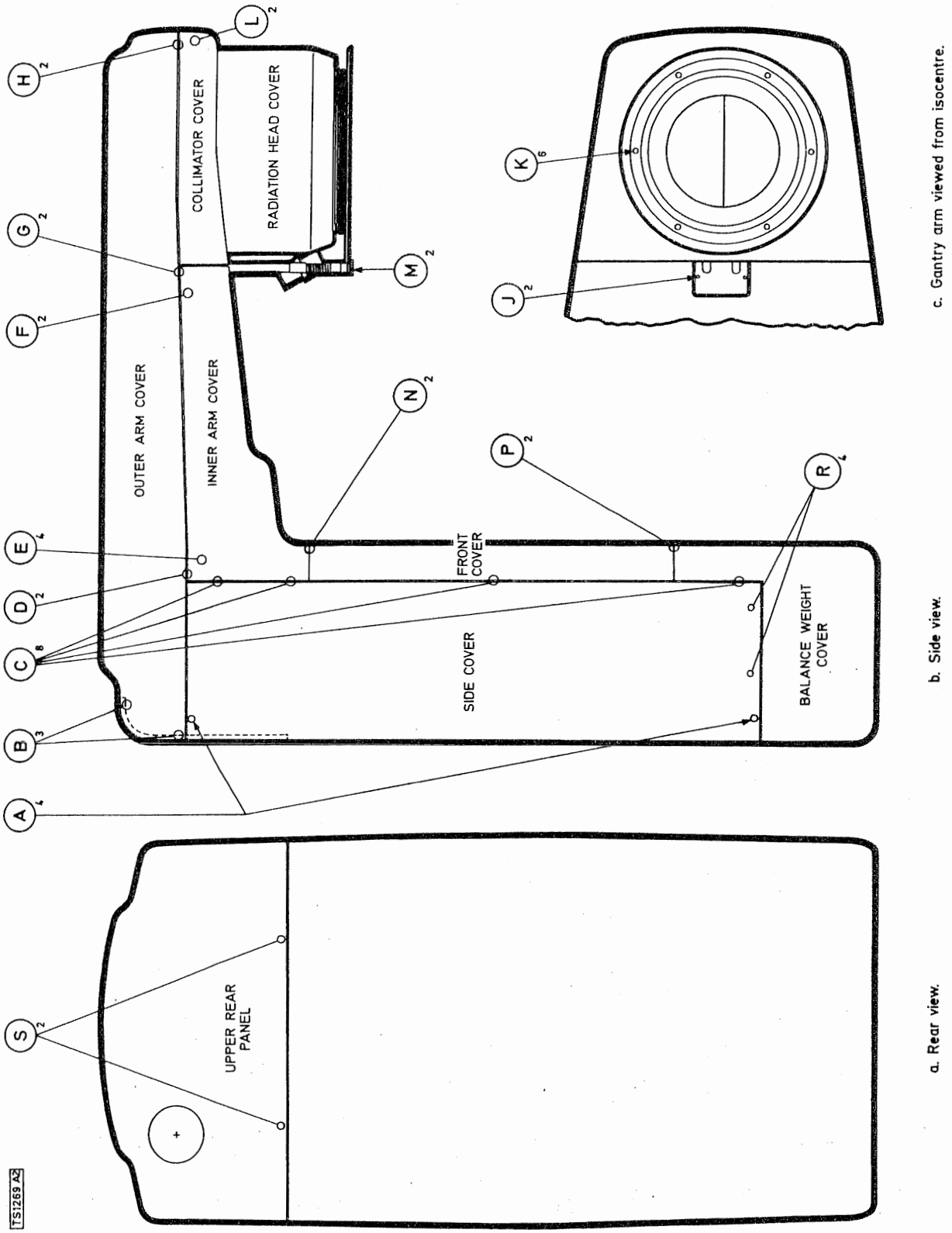
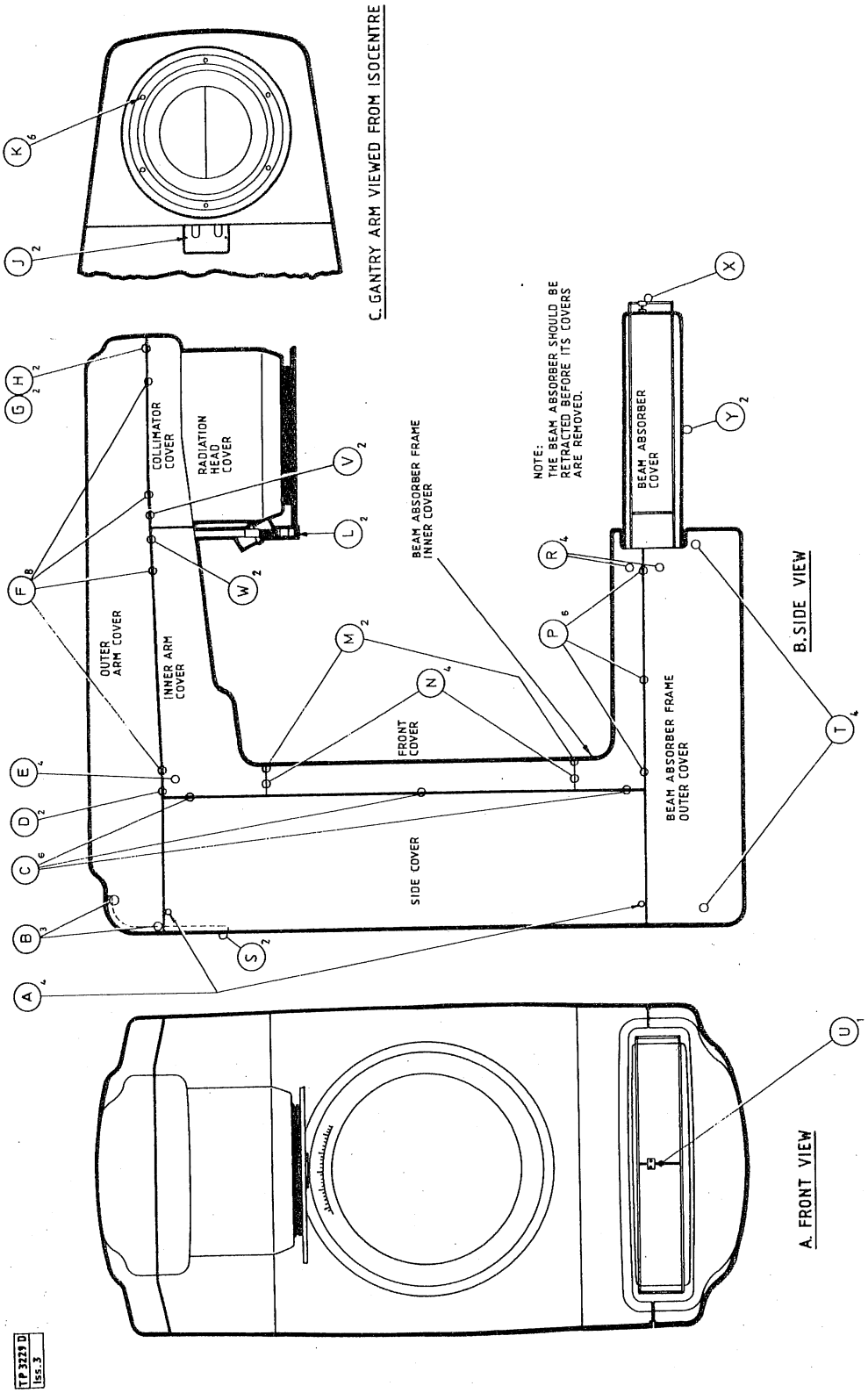


Figure 8: Gantry Covers Removal Guide, non-beam absorber M/C's


C. GANTRY ARM VIEWED FROM ISOCENTRE
COLLIMATOR COVER
RADIATION HEAD COVER
OUTER ARM COVER
INNER ARM COVER
BEAM ABSORBER FRAME INNER COVER
FRONT COVER
SIDE COVER
BEAM ABSORBER FRAME OUTER COVER
BEAM ABSORBER COVER
NOTE: THE BEAM ABSORBER SHOULD BE RETRACTED BEFORE ITS COVERS ARE REMOVED.
B. SIDE VIEW
A. FRONT VIEW
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Chapter 1: GENERAL INFORMATION

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1. INTRODUCTION

The SL75-5 Linear Accelerator (Linac) is a compact isocentric megavoltage X-ray therapy machine producing X-rays at an energy preset in the range 4 to 6 MV. Stationary or moving-beam treatments can be given, and a motorised wedge filter system can be used to produce asymmetric fields. Patient safety of a high order is provided by a dual-channel dose control system, forming part of a microprocessor-controlled system with select-and-confirm operational routines and comprehensive fail-safe interlocks.

2. BRIEF DESCRIPTION

The SL75-5 comprises the following main items of equipment:

- Rotatable Gantry,
- Gantry Support Frame Assembly,
- Modulator Cabinet,
- Monitor and Control Cabinet (MCC),
- Treatment Control Cabinet (TCC),
- Treatment Control Terminal (TCT),
- Pendant Movements Controller,
- Treatment Room Display (24-inch VDU),
- Water Cooler.

Referring to Fig. 1, the linear accelerator is carried in an arm which forms part of the rotatable Gantry. This is mounted on a Support Frame Assembly that also provides a mounting for the Modulator Cabinet and MCC. These items, together with the Movements Controller and Treatment Room Display, are situated in the treatment room; other main items are located in suitable areas outside (see Volume 1).

A schematic diagram of the SL75-5 is shown in Fig. 2. Pulses from the p.r.f. generator in the TCC trigger the Modulator which produces high-voltage, negative-going pulses that are fed to a pulse transformer in the Gantry. From here, pulses are fed simultaneously to the magnetron and electron gun cathodes. The magnetron generates pulses of microwaves at a nominal frequency of 2998 MHz and these are launched into the accelerator waveguide where they interact with electrons emitted by the electron gun. The accelerator waveguide is maintained at a high vacuum (about 10^{-6} torr) by means of an ion pump. Energy is transferred from the travelling wave to the electron beam which is thereby accelerated and emerges from the output end of the accelerator waveguide with a considerable gain in energy. The electron beam then passes along a drift tube into a bending chamber where, under the influence of a transverse magnetic field, it is bent through

approximately 98 degrees and then strikes a tungsten target to produce X-rays. Beyond the target is the radiation head consisting of a fixed collimator and a rotatable diaphragm system for field shaping. A flattening filter is attached to the collimator to produce a flat X-ray field. Directly below this filter is the ionisation chamber which is used to monitor beam intensity for the dual-channel dose control system, and to provide signals for the servo-systems maintaining field flatness.

The Modulator Cabinet houses the circuits which provide high-voltage, short-duration repetitive pulses for driving the magnetron and electron gun in the Gantry. The H.T. power requirements of the Modulator are provided by the H.T. power supply in the Gantry Support Assembly.

The Monitor and Control Cabinet contains monitoring circuits concerned with particular Linac functions, also the control circuits for certain servo-systems and for motorised movements in the Gantry. The basic mains power distribution area and several low-voltage power supplies are incorporated.

The Treatment Control Cabinet (Fig. 5) comprises two lockable compartments; the lower compartment contains a connector panel at which the cables interconnecting the TCC and TCT are terminated; the upper compartment contains a lockable drawer with a small recessed control panel in its front. Inside the drawer is the engineer's control panel for switching on and bringing the Linac up to operational readiness. This includes checking the machine performance (as during maintenance) and selecting the p.r.f. Also contained in the drawer are the microprocessor and printed-wiring circuit boards for treatment setting-up, monitoring and control functions initiated from the TCT. Transfer of control to the TCT is by means of a key-operated Off/Standby/Preparatory switch on the front panel of the drawer. A battery powered liquid crystal display of the delivered dose is also provided on the panel for reference in case of mains failure.

The Treatment Control Terminal (Fig. 3) is a desk-top console fitted with an alpha-numeric keyboard, a numeric keypad, a 12-inch VDU, paging buttons, and function switches for Treatment Start, Interrupt and Terminate. An AUTO SET-UP push button switch is additionally fitted but is not functional unless this optional facility is incorporated. The operator enters the treatment data by means of the keyboard and keypad, in response to a sequence of prompt messages on the VDU. In the case of a moving beam treatment, the required starting and stopping angles are additionally entered at the TCT. The microprocessor control system automatically provides a safety stop angle.

When a wedged field is required, in addition to entering the total dose in monitoring units required, that proportion of the dose to be delivered via the 60° wedge filter is entered. The period of insertion of the wedge filter is automatically controlled by the microprocessor to achieve the effective wedge angle required. In the case of a moving beam treatment with wedged field, the wedged portion of the treatment dose is given over the initial arc and the non-wedged portion of the dose is given over the return arc of rotation, all automatically. If incompatible data is entered, the VDU will indicate the permitted options for selection before prompting the next entry. Treatment cannot be started until the settings are completed satisfactorily. An equipment

fault if present would be indicated on the VDU. Fault indication is also given by the lighting up of the appropriate inscription on the engineer's monitor panel of the TCC. When READY TO START is displayed on the VDU, treatment may be commenced by pressing the START button and, after the correct dose has been delivered, irradiation is terminated automatically. If the primary dose channel should fail to terminate irradiation, a secondary dose channel and a time channel provide termination backup. All three channels are checked for correct operation at every treatment.

The pendant-type Movements Controller (Fig. 4) provides the speed and direction controls for the motorised movements, i.e. gantry rotation, radiation head (diaphragms) rotation, field size (diaphragms aperture) setting and P.S.S. table height. A spring-loaded safety hand-switch must be depressed before any movement can be effected. There is a Stop Motors push-button for use in an emergency, and a motors reset push-button; also a Touchguard warning light and override switch to enable gantry movement away from an obstruction. The controller also carries switches for the optical aids to patient alignment (field defining lamp and source-skin distance meter) and for dimming the room lights. A 'Next Page' switch is fitted for use with the optional Vericord (treatment verification and recording) system.

A VDU in the treatment room gives a read-out of the Gantry (and Patient Support System) movements for setting-up purposes. When the Linac is used in conjunction with a Vericord treatment verification and recording system, a number of treatment-data pages may also be displayed, in sequence, using the 'Next Page' push-button switch on the Movements Controller. Where Vericord is fitted, an optional second VDU can be provided in the treatment room. A switch on the Movements Controller selects the second VDU between the stand alone and Vericord real time displays.

Associated with the SL75-5 is some form of patient support system. Two Philips types are available. Each consists of a motorised under-floor turntable which carries a motorised vertical movements assembly on top of which is mounted the treatment table. The table is provided with longitudinal and lateral motorised movements, and has removable panels to facilitate treatment from below. In the case of the ram-type P.S.S., a stretched plastic sheet supports the patient when panels are removed. Both types of P.S.S. have a movements control box on each side, at opposite ends of the treatment table. The position of the movements are indicated by scales on the P.S.S. and are numerically displayed on the treatment room VDU.

3. SYSTEMS

The equipment comprises a number of functional systems; the principal ones are listed below:

- Modulator system,
- Microwave system,
- Automatic frequency control system,

- Vacuum control system,
- Electron gun control system,
- Beam transport system (focusing, centring and beam bending),
- Movements control system,
- Water Cooling system,
- Dose control system,
- Interlock system.

Circuit descriptions and maintenance information for these systems are provided in this Manual.

4. MAINTENANCE OF THE EQUIPMENT

Preventive maintenance schedules are given in Volume 1. These are intended to serve as a guide to routine maintenance on the SL75-5 over a three-year period. In addition, routine checks of performance should be carried out to provide the data listed in the SL75-5 Log Sheet.

The following points concerning general maintenance should be observed at all times:

- Study the data recorded in the SL75-5 Log Sheets at frequent intervals to see whether any persistent minor faults or undesirable trends require attention.
- Arrange that any repairs involving shut-down of the vacuum system are carried out so that the vacuum system is operational again in the shortest possible time.
- In general, if a section of the equipment has been operating satisfactorily, do not make any adjustments to it.

5. CUSTOMER RECORDS

The customer should maintain some form of records for the equipment and a suggested scheme for this is as follows:

(1) Daily Log Book : this records day-to-day operation of the equipment including L.T. and H.T. hours, meter readings, major faults and persistent minor faults, gun filament and magnetron replacements.

Note: It is recommended that the SL75-5 Log Sheets be used for this log book.

(2) Maintenance Log Book : this records which preventive maintenance schedules have been carried out and notes any subsequent action required, records any repairs made and details any modifications to units or systems.

(3) Spares Record : this provides a check on all spares held and indicates items to be re-ordered.

6. DRAWING SYSTEM

For efficient use of the documentation relating to this Linac, it is necessary to know the drawing system involved. The Philips system of drawing numbers is based on a 12-digit code. In the MEL usage of the system, the first seven digits define the type of machine in the SL75 series of Linear Accelerators; in this case 4513 326 refers to an item designed specifically for the SL75-5. Where a part was originally designed for another type of machine its original drawing number is retained, e.g. a 4513 325 number refers to a part designed for the SL75-20. Exceptions are major sub-assemblies that are common to several types of SL75 machines. For instance, the current type of TCC has 4513 399 etc. as the basis of its drawing number series, and new designs of printed-wiring boards (i.e. since June 1978) are designated 4513 390 etc.

The next group of four digits in the 12-figure code identifies a specific part of the machine (see Table below). Here, the eighth digit refers to a main section of the machine, e.g. 4513 326 6000 identifies the MCC. The ninth digit identifies a sub-section, e.g. 4513 326 6100 is for the MCC, Level 1, but there are notable exceptions to this, mainly in Level 1 of the MCC where PWBs originally located at Level 2 and accordingly numbered 4513 326 6274 and 5 are now situated in Level 1.

Number identifying a specific part of the machine

Part of machine	4-digit number series
System diagrams	0000
Mechanical assemblies	1000
Gantry Support Assembly	2000
Modulator	2500
Gantry	3000
Gantry arm	4000
Radiation head	5000
MCC	6000
Level 1	6100
Level 2	6200
Level 3	6300
Level 4	6900*
TCC and TCT	7000
(Patient Support Systems	8000)
Movements Controller	0860

* - See later 'Note'

The tenth and eleventh digits are allocated to individual parts within a sub-section and the twelth digit indicates the Issue number of the drawing. This is normally quoted as zero, which is an instruction to use the latest issue of the drawing. However, the actual issue number, when used, forms a 12th and 13th digit pair, e.g. 4513 329 6100 Issue 1 is written as 4513 329 6100 01. The presence of an 'A' after an issue number simply indicates that the change is a correction to the drawing information, not a design change.

In addition to the drawing number code, a further set of 'Group' numbers is used to specify the type of information contained in the drawing, e.g. Group 130 for circuit diagrams, Group 121 for parts lists etc.

In cases where a drawing extends to more than one sheet, a consecutive sheet number is allocated, e.g. 4513 399 7603 0 Group 130 comprises four sheets numbered 1 to 4. The Group and Sheet number may be shown in composite form e.g. Group 130-1, 130-2 etc.

7. CIRCUIT REFERENCES

Identically referenced components situated in different parts of the machine are identified by including in their circuit references the eighth and ninth digits of the drawing number code (see previous Table) to indicate their location. Some examples are:

Plugs and sockets	:	PL70-A defines plug A in the TCC.
		SK40-A defines socket A in the gantry arm.
		RL38-A defines relay A in the Ion Pump power supply on the gantry.
Relays and contactors	:	CON60-A defines contactor A in the MCC.
Printed wiring boards	:	PWB61-A defines board A in the MCC at Level 1.
		PWB76-FF defines board FF in the TCC (Area 76).
Switches	:	S76-2 defines S2 in the TCC (Area 76).
		Switch-poles are designated by a further suffix e.g. S76-2A, S76-2B, etc.

NOTE

One major exception to the rule occurs in the MCC where the number of Levels has been reduced so that Level 9 (4513 329 6900) is now Level 4; furthermore the components in Level 4 are given the overall MCC reference code '60' rather than the sub-section reference, which for Level 4 would be 64.

Resistors, capacitors and solid-state devices, however, are not given any location coding but are numbered from 1 upwards in any given location as required.

Where it is required to refer to a pin or terminal of a component (see above examples), the component reference is condensed e.g. PL70-A becomes PL70A and the pin identification is added as PL70A-DD, for example. In circuit diagrams where the type of component is obvious from the circuit symbol, the prefix PL may be omitted, leaving only 70A-DD against the symbol.

8. INTERCONNECTIONS

A large proportion of the wiring interconnections are made using multi-pin plug and socket connectors, see Inter Unit Cabling diagram 4513 329 0001 Gp. 131-1 in Volume 3. Individual pin allocations in these connectors are, in general, maintained throughout wiring runs, e.g. pin PL60E-w in the MCC connects to pin SK70A-w in the TCC, pin PL60J-4 connects to pin SK89A-4 in the P.S.S. Where, however, different types of connectors are used at each end of a cable, the rule cannot be followed and the relevant system circuit diagram will have to be consulted, e.g. plugs PL60-A and B connect to terminal strips TS1, 2 and 3 in the Gantry.

9. SYSTEM DRAWINGS

In addition to the detailed circuit drawings for each part of the machine, (PWBs, MCC Levels etc.) system circuit drawings are provided which show the interconnections between the items forming the main control systems. These drawings should prove useful for fault finding and their drawing numbers are in the 0000 series of the previously given Table, e.g. 4513 326 0002 is for the AFC system. For full details of the circuit in any area, however, refer to the primary circuit diagram for the area concerned, e.g. 4513 326 7575 0 for the AFC Preamplifier and Detector board.

10. CONVENTIONS FOR MEASUREMENT OF LINAC OUTPUT RADIATION

Measurement of Linac output radiation is normally made in a plane perpendicular to the output beam. Some form of reference system is necessary to specify points in this plane and, for this, the following terminology and conventions are customarily used (see Fig. 5):

(1) Radiation beam axis : the axis from the radiation source which passes through the centre of the radiation field.

(2) Measurement plane : the plane at right angles to the radiation beam.

(3) Longitudinal axis : denoted as the G-T axis, this is the projection of the gantry rotation axis through the isocentre; (it can also be an axis parallel to this if the measurement plane is below or above the isocentre).

G - represents the region of the G-T axis between the isocentre and the gantry face, e.g. G9 cm indicates a point 9 cm from the isocentre (or other centre of the measurement plane) in the direction of the gantry face.

T - represents the region of the G-T axis between the isocentre and the treatment room main area.

(4) Transverse axis : denoted as the A-B axis, this is the axis in the measurement plane at right angles to the G-T axis and the central axis.

A - represents the region to the right hand side of the G-T axis when viewed facing the Gantry-angle scale and looking down from the radiation source.

B - represents the region to the left hand side of the G-T axis when viewed facing the Gantry-angle scale and looking down from the radiation source.

11. CUSTOMER'S CONNECTIONS TO THE EQUIPMENT

External connections to the equipment are made via terminal strip TS1 at Level 4 of the MCC. These connections include the main 3-phase a.c. electrical supply from the main isolator (See 'Warning') and various safety interlock and control circuits associated with facilities that are the client's responsibility. The customer is required to supply and fit the main isolator and an interface terminal block for the other circuits. Philips are responsible for connecting these to TS1 in the MCC.

NOTE

This interface does not include connections associated with optional data readout or treatment verification facilities which are made direct to the TCC.

WARNING

BEWARE OF MAINS VOLTAGES REMAINING ON LEVEL 4 OF THE MCC WHEN ONLY THE MAIN 3-PHASE SUPPLY IS ISOLATED.

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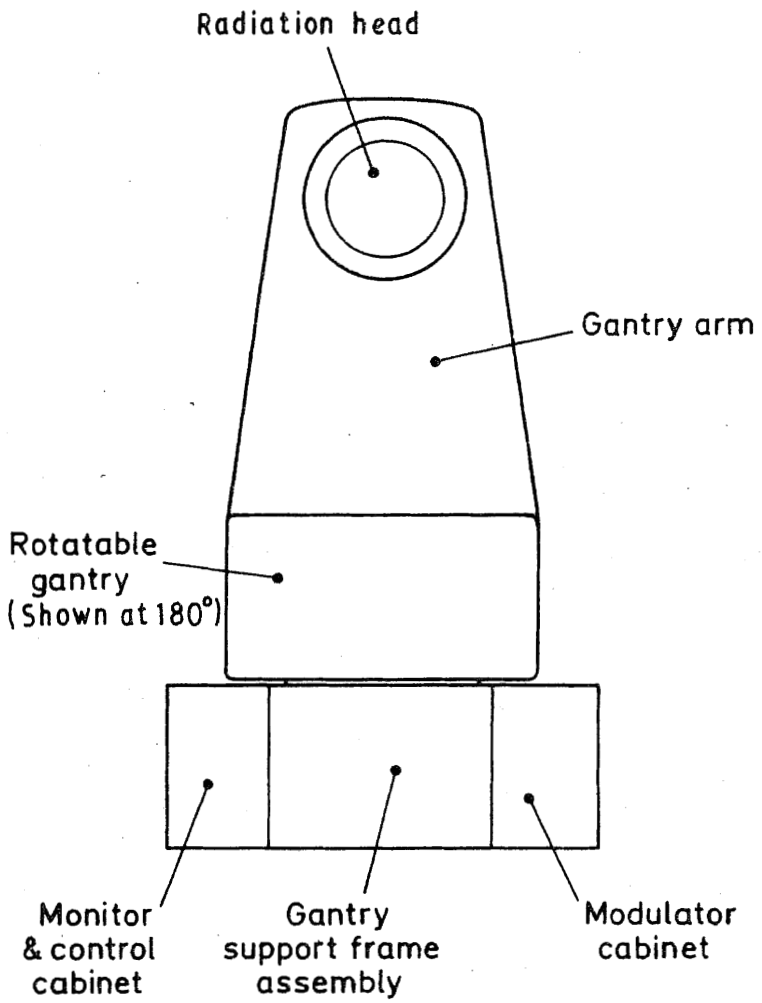


Figure 1: SL75-5 Linear Accelerator, plan view showing layout of sections

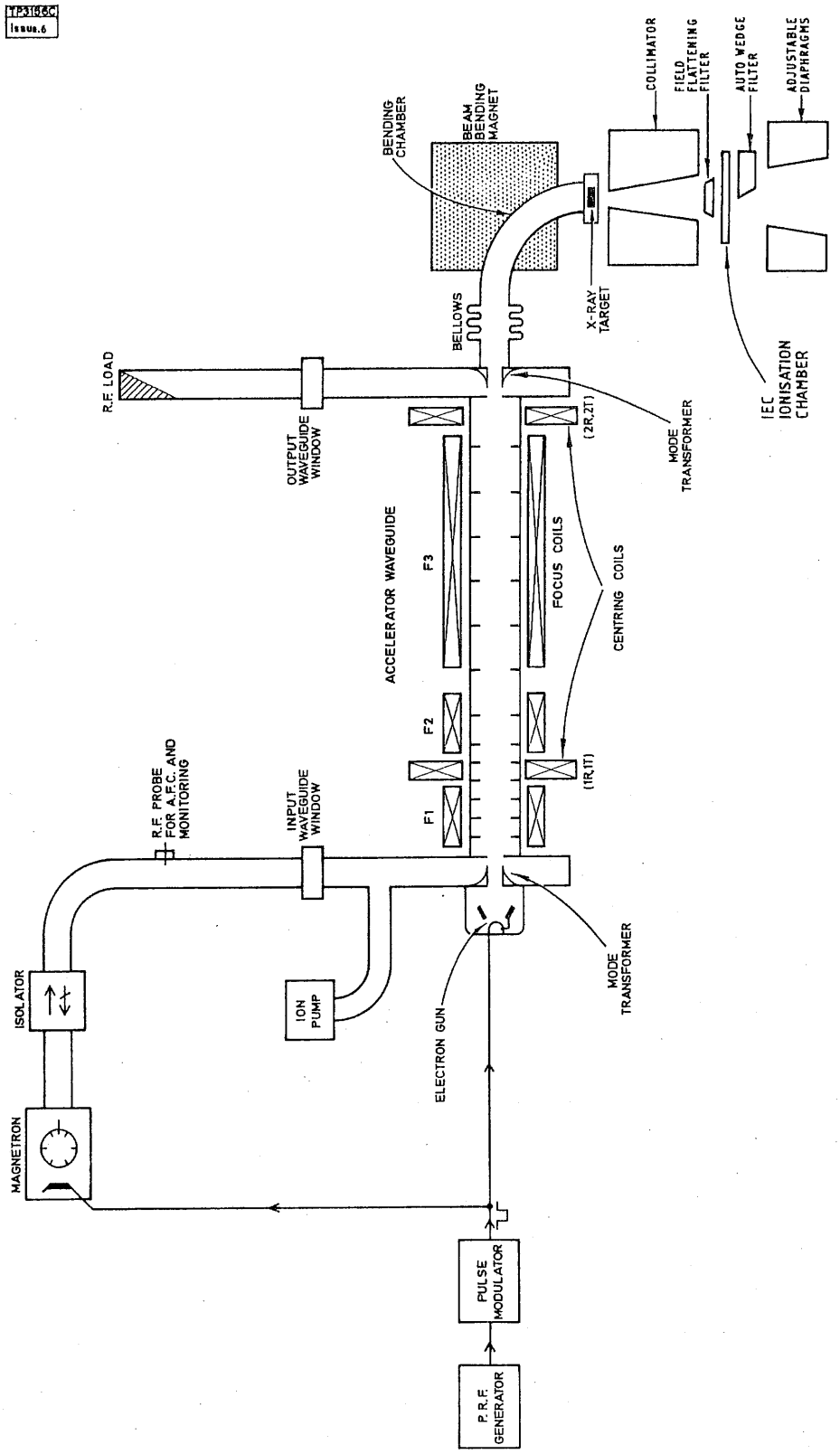
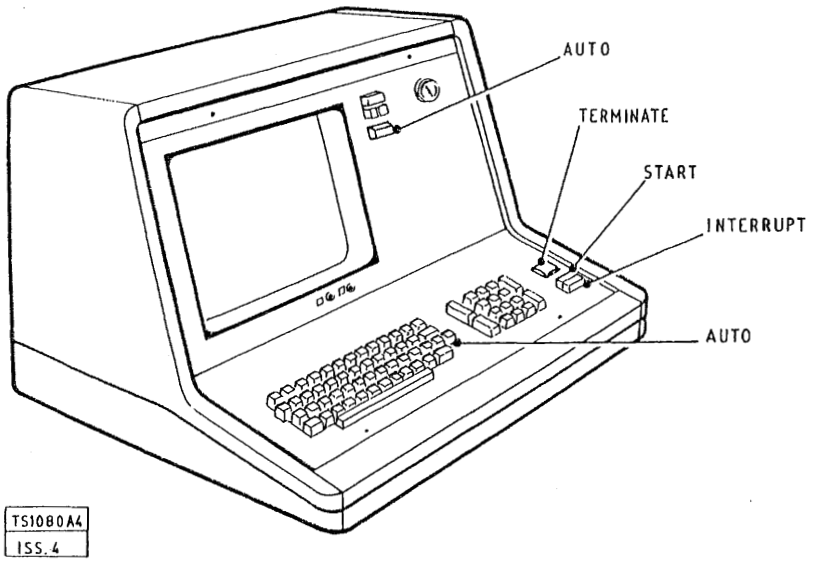
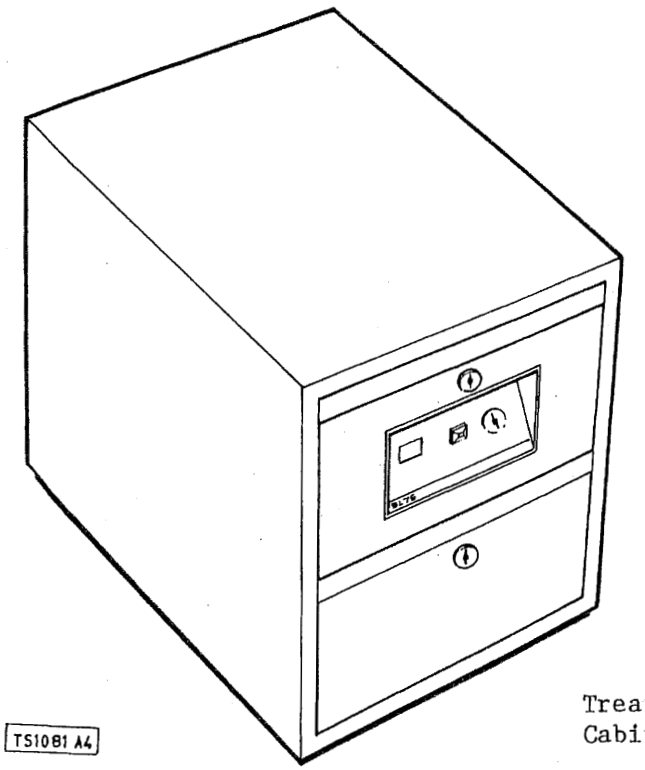


Figure 2: SL75-5 Linear Accelerator, schematic diagram



Treatment Control
Terminal (TCT)



Treatment Control
Cabinet (TCC)

Figure 3: Treatment Control Cabinet and Terminal

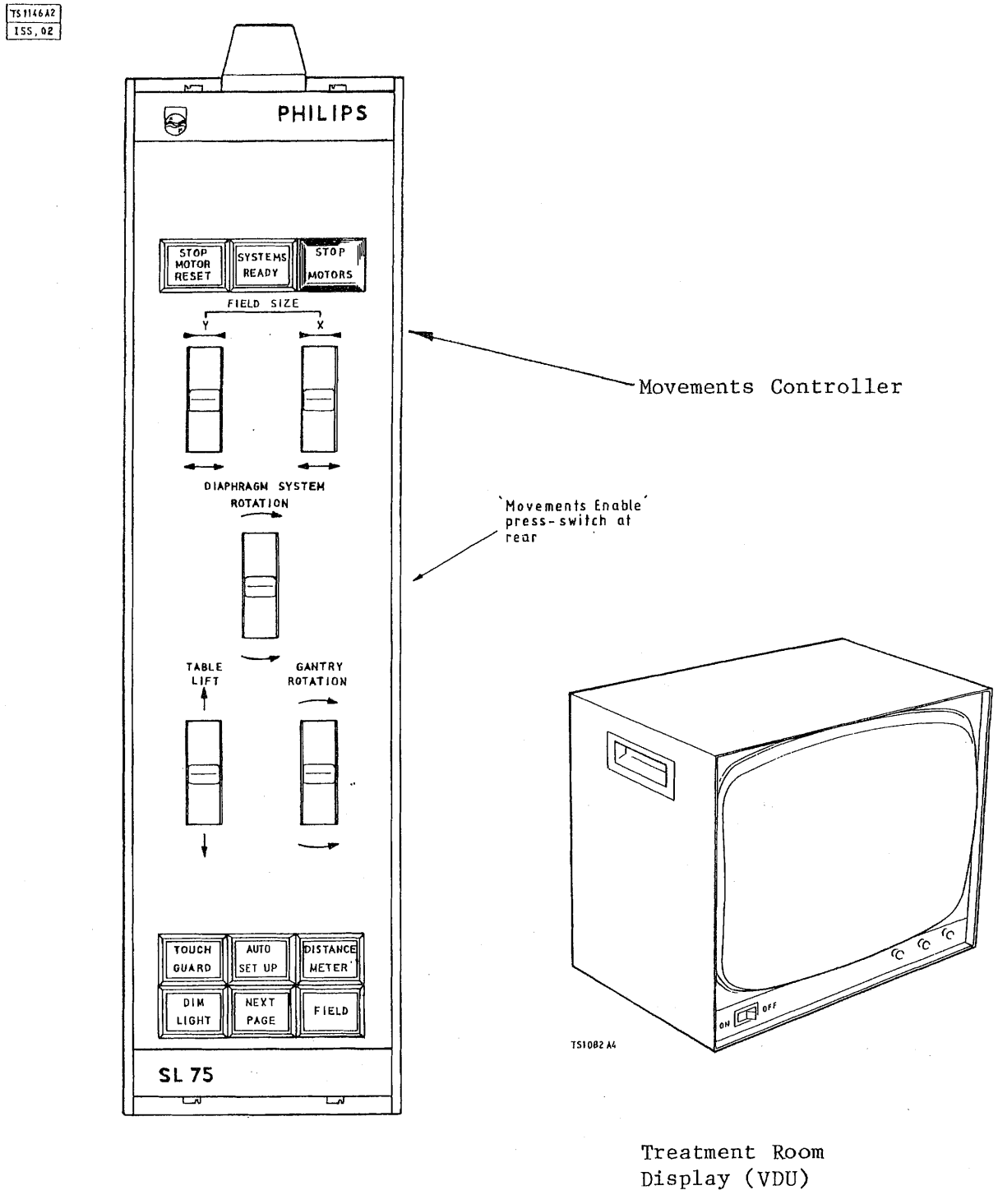


Figure 4: Movements Controller and Treatment Room Display

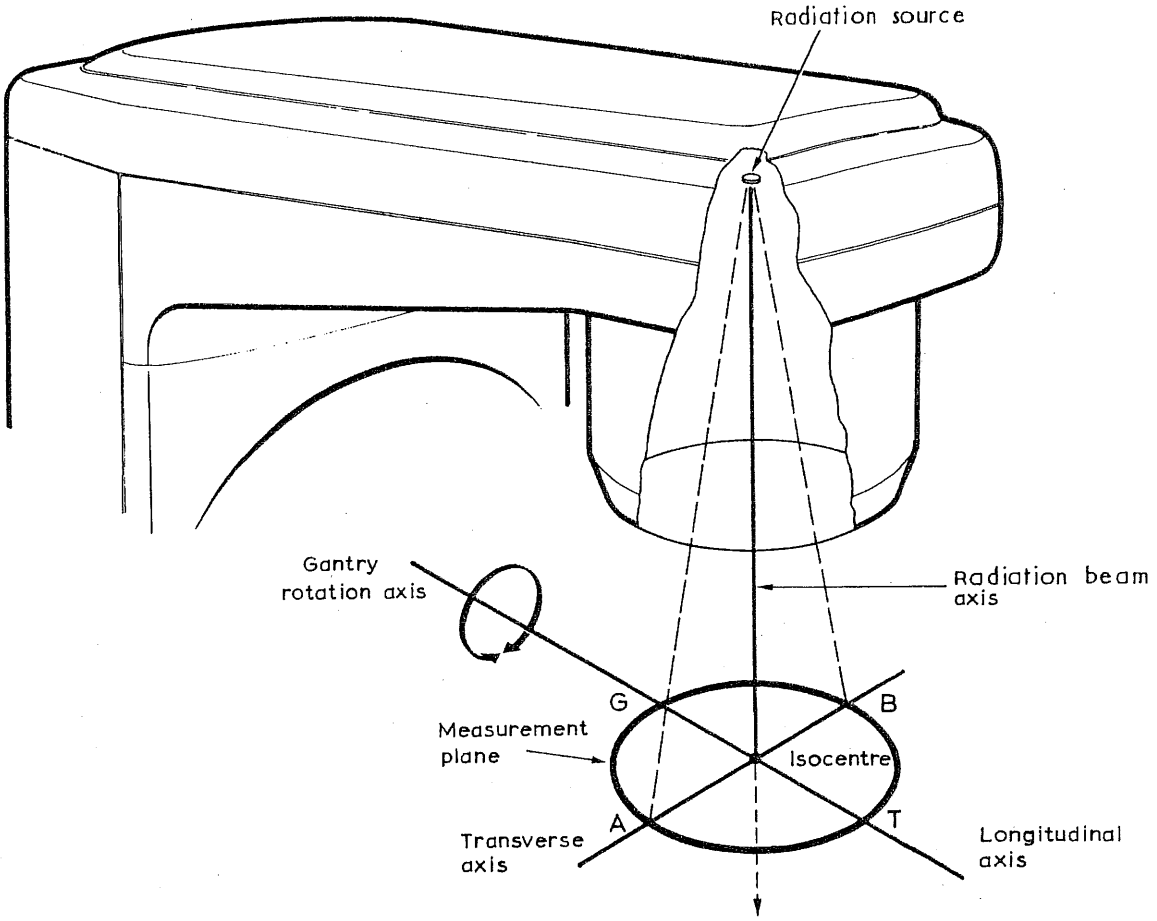


Figure 5: Reference system for output measurements

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1. GENERAL INFORMATION

The Gantry System consists of two main sections; a fixed Support Frame Assembly and a rotating Gantry. Together these provide the means by which the Linac is positioned for delivering the output radiation dose.

The Support Frame Assembly (Fig. 1) comprises a floor frame, and a support frame carrying the bearing on which the Gantry rotates. The support frame also provides a mounting for the Modulator and MCC cabinets. The floor frame is firmly fixed to a steel installation plate bolted in the bottom of a shallow cavity in the treatment room floor.

The Gantry (Figs. 2 & 3) consists of a basic central frame to which is bolted the gantry arm. The radiation head is attached to the end of the arm. The optional beam absorber (Fig. 3) is attached to the gantry opposite to the arm.

Mounted within the Gantry System are a number of components which are part of the various systems described in later chapters (Vacuum, Microwave, etc.).

Circuit diagrams:

- Gantry Support Assembly (including Modulator) : 4513 329 2000 0, Gp.130, Sht.1
- Gantry : 4513 326 3000 0, Gp.130, Shts. 1 & 2

2. DETAILED DESCRIPTION

2.1 FLOOR FRAME

The rectangular floor frame, measuring 1680 mm by 913 mm (5 ft.6 in. by 3 ft. approx.), is fabricated from 5 in. (127 mm) channel-section steel skinned on top and bottom with 6 mm ($\frac{1}{4}$ in.) steel plate. The frame is firmly fixed to the installation plate in the floor cavity by means of ten clamp bolts. At the forward end the side members are extended to provide jacking points; these extensions also prevent any possibility of the part-assembled Gantry System toppling forward during handling prior to installation.

2.2 SUPPORT FRAME ASSEMBLY

The support frame assembly is bolted to the rear end of the floor frame. It consists of a braced vertical frame made from 5 in. (127 mm) channel-section steel with a 25 mm (1 in.) steel plate panel welded between the vertical members.

This panel is machined to accept the fixed journal of the bearing on which the Gantry rotates. Other members are attached to the support frame assembly and fitted with covers to form a cabinet which houses the following items of equipment:

- Gantry drive motor, clutch and gearbox;
- H.T. power supply for the Modulator including the H.T. transformer rectifiers and smoothing components (see Chapter 6: Modulator System);
- Cable and water-hose reeling facilities;
- Gantry rotation limit switches, gantry angle readout potentiometer and water flow interlock switches;
- Water flow and pressure gauges.

The rear side members of the cabinet framework have hinge blocks and pivots, at top and bottom, for mounting the Modulator (left-hand side) and MCC (right-hand side), as viewed from the front of the Linac (radiation-head end).

CAUTION

THE DETACHABLE UPPER REAR CROSS-MEMBER OF THE CABINET FRAME MUST NOT BE REMOVED WITHOUT FIRST DEMOUNTING OR SUPPORTING THE SIDE CABINETS (MODULATOR AND MCC).

2.3 GANTRY

The rotating Gantry has a basic steel structure with a tubular flanged support at one end for the gantry arm. The basic structure is of $\frac{1}{2}$ in. (12.7 mm)

material; the rear panel is reinforced and machined to accept the moving journal of the Gantry bearing. Mounted on the sides of the structure are the following items (see Figs. 2 & 3).

- Gun filament and magnetron filament power supplies (see Chapter 9 : Beam Control, and Chapter 7 : Microwave System respectively);
- Focus power supplies (three) (see Chapter 9 : Beam Control);
- Ion pump power supply and ion pump (see Chapter 8 : Vacuum System), Vacuum tap and port;
- Gantry Distribution Panel;
- Rectangular waveguide system including magnetron, high-power isolator (see Chapter 7 : Microwave System), air pressurising valve and gauge;
- Pulse shaping network and pulse transformer (see Chapter 6 : Modulator System);
- A.F.C. cavities (see Chapter 7 : Microwave System);
- Water flow switches;
- Optical system power supplies.

The gantry is clad in protective covers as shown in Figs 8 and 9. The covers are moulded in polyurethane integral skin foam, and coated on the inside with a fire resistant paint. On beam absorber machines, the covers are moulded in GRP.

The gantry front cover incorporates the gantry angle scale assembly. The circular scale is calibrated from 0° to 360° and rotates with the gantry. Inside the scale is a disk with a pointer at the top. The disk is freely pivoted at its centre (i.e. the gantry rotational axis) and is weighted at the bottom so that the pointer always points vertically upwards. There are 'windows' in the circular scale at positions corresponding to -20°, -10°, 0° and +10° with respect the clockwise and counter-clockwise limits of gantry rotation. Gravity operated warning symbols are displayed automatically in the appropriate set of windows, according to the direction of gantry rotation.

The gantry locking pin is kept in its working position, bolted over a hole in the back wall of the rotatable gantry, in the vicinity of the magnetron, but inverted so that its pin is not engaged with the hole. Four mating holes are provided at 90° intervals in the stationary bearing plate of the Gantry Support Frame Assembly, behind. It is preferable to select the hole that comes into alignment when the Gantry is set at 180° (radiation head at its lowest position). Care should be taken when fitting the steel pin to prevent it from coming into contact with the magnetron magnet. Remove the two bolts mounting the locking pin assembly to the Gantry, invert the assembly and insert the pin through the aligned holes, then bolt it in place again.

2.4 GANTRY ARM

The gantry arm (Fig. 4) consists of a steel tube with a fabricated box at one end; it is attached to the flanged support on the basic structure. Mounted in and on the arm are the following items:

- Accelerator waveguide together with electron gun, centring coils and focus coils;
- R.F. load;
- Gantry preamplifier.

Within the box at the end of the arm are the bending chamber, bending magnet (with adjustable shunt) and target block. Also in the box are a number of blocks of shielding material for attenuating stray radiation around the target.

The accelerator waveguide is supported by an internal flange at one end of the arm and by a centralising flange at the other. It consists of a cylindrical copper waveguide with copper irises at periodic intervals along its length. The structure is maintained at a constant temperature by cooling water flowing in channels in the waveguide walls. A set of four focusing coils and two sets of centring coils are mounted directly on the waveguide and two other concentrically wound sets of focus coils fit over the electron gun end of the waveguide after it has been assembled in the arm. These coils are used to obtain efficient transport of the electron beam from the gun to the output drift tube. The travelling waves propagated down the accelerator waveguide transfer some power to the electron beam and some to the waveguide walls. The microwave power remaining at the output end of the accelerator is extracted by a mode transformer and is dissipated in a power-absorbing load.

The electron gun contains a directly-heated cathode which has high-voltage negative pulses applied to it from the Modulator. The resulting pulses of electrons are formed into a beam by a focusing electrode and then are injected through a hole in the anode plate into the accelerating waveguide. The gun consists of a tubular metal section incorporating the cathode filament, sealed to a glass section carrying the high-voltage leads. The gun is attached to the waveguide by a demountable vacuum joint which permits easy removal of the gun for filament replacement.

At the output end of the accelerator waveguide, the electron beam travels along a drift tube and enters the bending chamber where it is bent through 98 degrees by a magnetic field to strike a tungsten target. The permanent magnet used for beam-bending has an adjustable shunt across its pole-pieces. This is set up in the factory so that the field strength at the bending chamber is such that only electrons of the required energy are correctly deflected to strike the target centrally and perpendicularly. Electrons outside the correct energy are deflected either too much or too little and so miss the target altogether or strike it outside the focal spot area.

2.5 RADIATION HEAD

- Circuit diagram : 4513 326 3000, Gp. 130, Sht. 2

The radiation head (Figs. 5 & 6) is flange-mounted to the box at the end of the gantry arm. It provides the means for controlling the size of the radiation field and is fitted with optical and mechanical aids for setting up the required field. Two main sections make up the radiation head; a fixed collimator and a rotatable diaphragm system.

2.5.1 Collimator

The primary collimator consists of a central cylinder of heavy metal with a conical bore which defines the X-ray beam angle. This is surrounded by a lead-filled steel casting. The effective focal spot size is approximately 4 mm and the half angle of the beam (as defined by the bore of the collimator) is 14 degrees. This is equivalent to a field size of 50 cm diameter at 1 metre from the target. Radiation outside the limits of the beam is reduced to a very low level.

Where a beam absorber is fitted to the gantry, a special primary collimator is fitted in which the half angle of the bore is reduced to 11°. This defines a field which is within the area of the beam absorber.

2.5.2 Field Flattening Filter

Secured to the collimator, at the lower end of the conical bore, is a field-flattening filter. This produces an X-ray field that is uniform in intensity to within close limits.

2.5.3 Ionisation Chamber

The radiation field from the Linac is monitored by an IEC ionisation chamber mounted directly after the turret. The chamber is made up of three individual chambers, Dose 1, Dose 2 and Servo, stacked together. Each individual chamber consists of a "collector plate" and a "polarisation plate", separated from each other by an annular support. The collector plates (+ ve) are insulated from each other and from the polarisation plates which are connected to a common -300V supply. The chambers are filled with ordinary air. Dose chambers 1 and 2 provide dose signals for a dual-channel dosimetry system. The Servo chamber is stacked between dose chambers 1 and 2. Its collector plate has six sections in the form of three pairs of segments arranged symmetrically about the centre of the field to detect field imbalance which is reduced to a minimum by the following servo systems:

- Centring servo along the longitudinal axis G-T (see Fig. 6 in Chapter 1). The servo controls the current in the centring coil 2R (see Fig. 1 in Chapter 9).

- Centring servo along the transverse axis A-B. The servo controls the current in the centring coil 2T.

- Gun servo along the longitudinal axis G-T. The servo controls the electron gun filament current and hence the energy of the electrons entering the accelerator waveguide which affects the curvature of the electron beam in the bending chamber.

Any resulting imbalance is monitored as a measure of field flatness error.

It will be seen from the circuit diagram that all connections are made to the ionisation chamber via the Gantry Pre-amplifier Assembly. A -300 volts supply required for the operation of the ionisation chamber is obtained from the MCC, Level 3. For functional details of the ionisation chamber, refer to Chapter 9 - Beam Control and Chapter 5 under 'Dose Measurement'.

2.5.4 Auto-Wedge Filter Assembly

Interposed between the ionisation chamber and the diaphragms is an automatically operated wedge filter assembly controlled by the TCT/TCC. A 60° wedge filter is automatically driven into position by an electric motor at the start of a wedged field treatment and is withdrawn when a predetermined proportion of the total dose has been delivered, so that the effect of a wedge filter whose angle is variable between 0 and 60° is obtained.

The +24 volts supply is initially connected to the motor M7 via the normally closed contacts of the Wedge In limit switch SC, SD and the contacts of relay RL-A which is energised from the TCC for arc therapy operation. Directly the wedge filter reaches its operative inwards position the Wedge In limit switch operates, thereby switching off the motor and connecting the +24 volts to the TCC instead, to signal the Wedge In condition. When the appropriate portion of the set dose has been delivered the TCC de-energises relay RL-A so that the +24 volts supply is applied to the motor in opposite polarity via the normally closed contacts of the Wedge Out limit switch. The wedge is thus driven outwards until it actuates the Wedge Out limit switch SA. This disconnects the +24 volts supply from the motor and signals the Wedge Out condition to the TCC for the remainder of the set dose to be given.

2.5.5 Diaphragms System

An electric motor (M1) drives the rotatable diaphragm system through a gearbox carrying a driving sprocket which engages in the head fixing ring. The field defining diaphragms can be rotated through an angle of 370 degrees. The motor is controlled by a thumbwheel on the Movements Controller, and the diaphragm system rotation is monitored by a precision potentiometer connected to the gearbox, giving analogue data which is converted to a digital readout of diaphragm system rotation (sometimes referred to as head angle) by the TCC and presented on the Treatment Room Display.

The diaphragm system consists of two sets of movable diaphragms which define a rectangular X-ray field. Each set of diaphragms is supported on linear bearings and is driven by a chain-drive linkage and electric motor (M2 for the inner diaphragms, M3 for the outer diaphragms). The diaphragms are also constrained by linkages to tilt so that the inner faces of the diaphragms are always aligned with the X-ray source at the target. The arrangement is such that the

diaphragms are balanced in all positions of the radiation head. In this way a sharply-defined field is obtained and any penumbra is as narrow as possible. For field sizes in excess of 35 cm by 35 cm (at 1 metre from the target), the field has rounded corners because of limits imposed by the collimator.

Limit switches are incorporated to avoid over-driving the diaphragms. The field size set by each pair of diaphragms is monitored by a precision potentiometer coupled to the motor gearbox, giving analogue data of the field size which is converted to a digital readout by the TCC and presented on the Treatment Room Display.

All electrical supplies to the rotatable part of the radiation head are fed through two flexible connector strips (retractiles). The electric motors for the head rotation and diaphragm movements are supplied from motor control circuits in the MCC.

2.5.6 Optical Field Defining System

Immediately below the auto-wedge filter assembly is a thin Mylar mirror. This is associated with a field-defining lamp that projects a beam of light through the aperture defined by the diaphragms, thereby indicating the field size and orientation on the surface being irradiated. Incorporated in the light source is a graticule which casts on the light field an image of a cross and a small triangle, thus defining the centre of the field and orientation of the wedge filter with the field. The lamp for this system is mounted on the side of the diaphragm system and is switched on using the appropriate push-button on the Movements Controller. Access to the mirror and other items in the head is obtained by taking off the head cover and withdrawing the Automatic Wedge Filter Assembly. Two lamps then illuminate the head interior.

2.5.7 Optical SSD Metering System

A second optical system is provided which indicates the distance between the radiation source and the patient's skin (SSD). The lamp for this is mounted on the touchguard supports close to the radiation head cover and is switched on by the appropriate push-button on the Movements Controller. It projects a scale onto the patient's skin and, where the scale coincides with the centre of the field (as defined by the crosswires image), the SSD is defined.

2.5.8 Shadow-Tray Accessory Coding

Provision is made for the automatic electrical connection of accessories which may be attached to the accessory ring of the radiation head, i.e. to energise the coding switches of the Shadow Trays. The binary signals from the coding switches identify the accessory. They are converted into a single analogue voltage by a high stability resistor R/2R ladder network (HSR) in the radiation head. This signal is further processed and stored by the TCC for use with the optional treatment verification and recording system (Vericord).

2.6 GANTRY PRE-AMPLIFIER ASSEMBLY

o Circuit diagram : 4513 326 4005, Gp.130

The three pairs of servo-control signals from the ionisation chamber are taken to the locally situated Gantry Preamplifier Assembly. It contains, on PWB40-A, six identical stages of operational amplifier with emitter-follower output. Their pulse signal outputs are a.c. coupled via coaxial cables to the TCC where the beam control systems are located. The Dose 1 and Dose 2 ionisation chamber signals are routed directly to the TCC via input and output coaxial connectors on the assembly which are interconnected internally; i.e. these signals are not buffered. Also routed through the assembly are the -300 volts supply to the ionisation chamber and a -300 volts return line from the ionisation chamber for supply monitoring.

2.7 BALANCE WEIGHTS

To counterbalance the mass of the Gantry Arm and Radiation Head, balance weights are carried on the rotatable Gantry (Figs. 2 and 3). These may be removed, with the Gantry locking pin in place and Gantry Arm downwards, to permit the Gantry Support Assembly and Gantry together to pass through a standard door opening.

2.8 BEAM ABSORBER

When the Linac is installed in a room whose walls do not offer sufficient radiation protection for personnel outside the room, the balance weights are replaced by a beam absorber. This optional extra provides an attenuation of 1000, and consists of a circular slab of lead weighing about 1000 kg supported on a carriage which can move out from and back towards the Gantry face on a pair of bars. When extended the beam absorber is directly in the path of the primary X-ray beam; however, because of limitations in physical size, it is necessary to reduce the X-ray field size. Beam absorber machines are therefore fitted with a special narrow angle collimator in the radiation head. Interlocks (see Chapter 3: "Interlocks") prevent the Linac from operating if the X-ray output is directed towards an unsafe area with the beam absorber retracted. The beam absorber is controlled by a switch on the movements controller. An indicator lamp inside the switch illuminates when it is necessary to extend the beam absorber.

2.9 VACUUM SYSTEM

The vacuum system consists of the interior volume of the accelerator waveguide, electron gun, input and output rectangular waveguide feeds up to the waveguide windows, output drift tube and bending chamber. Total volume is about 8 litres. The vacuum system is maintained at a pressure below 10^{-5} Torr by an ion pump at the gun end of the accelerator. For details see Chapter 8.

2.10 WATER COOLING

The water cooling system distributes a supply of temperature-controlled water to certain parts of the Gantry Support Assembly and Gantry. The water enters through an isolating tap on the support frame and then passes through flexible

hose to the Gantry. The return flow is through another isolating tap to the Water Cooler. Each separate circuit has an associated flow switch that breaks an interlock circuit if the flow fails. Details are given in Chapter 11.

3. MAINTENANCE INFORMATION

3.1 GENERAL

Maintenance information for most items on the Gantry can be obtained by reference to the chapter on the appropriate system; for example:

- Changing the magnetron : Microwave system : Chapter 7.
- Replacement of gun filament : Beam control : Chapter 9.
- Evacuation procedure : Vacuum system : Chapter 8.
- Gantry movements setting-up : Movement control system : Chapter 10.

3.2 ESTABLISHING THE ISOCENTRE

One method of establishing the isocentre is as follows:

(1) Rotate the Gantry to 0 degrees. Attach the mechanical front pointer to the radiation head and adjust the pointer so that the point is 100 cm from the target.

(2) Set up a vertical stand carrying a rigid pointed rod horizontally so that the point of the rod just touches the tip of the front pointer.

(3) Rotate the Gantry to 180 degrees and if the two points separate, observe the difference in vertical distance between the two points. Eliminate the difference by moving each pointer vertically by half the error.

(4) Rotate the Gantry to 0 degrees and check that the pointers still meet. If not, repeat the adjustments until the error between the tip of the rigid pointer and the front pointer does not exceed 2 mm on rotation. The point so defined is the isocentre.

4. RADIATION HEAD SETTING-UP PROCEDURES

4.1 SYMMETRY OF LIGHT FIELD WITH DIAPHRAGMS APERTURE

Check the symmetry of the optical light-field with respect to the diaphragms aperture as follows:

(1) Rotate the Gantry and the radiation head to 0 degrees.

(2) Set the diaphragms for a rectangular field e.g. 10 cm x 15 cm, so that the two axes are readily identifiable.

(3) Fasten a horizontal sheet of paper directly below the head and mark on it the edges of the light field, at four places.

(4) Rotate the head 180°. The edges of the light field should coincide with the four points previously marked. If not, mark the new edges of the light field and continue as follows.

(5) Slacken the four socket-head screws 'A' securing the Field Defining Lamp assembly (see Fig. 7) just sufficiently to enable the assembly to be repositioned slightly so as to halve the difference between the two sets of markings, in each axis. Resecure the assembly, making sure that the setting is not disturbed.

(6) Repeat steps (3) to (5) until the required symmetry is obtained.

NOTE

Any change made to the position of the field defining system will necessitate a subsequent check on the alignment of the Distance Meter scale with the crosswire image. It is advisable also to check the X-ray field size and position.

4.2 SETTING-UP THE X-RAY FIELD-SIZE INDICATION

Proceed as follows:

(1) With the gantry and radiation head at 0 degrees, set the field-defining diaphragms to an X-ray field size of 30 cm x 30 cm as indicated on the VDU display in the treatment room. Switch-on the field-defining light.

(2) Place an X-ray film, in its cover, horizontally at the isocentre; mark the film by pricking through the isocentre, as defined by the projected crosswires, and outline the optical field by pressure marks.

(3) Cover the film with 10 mm of tissue-equivalent material. Expose the film for density 2 (about 70 rads on Kodak X-OMAT-V). Process the film, and then use a densitometer to analyse the X-ray field. Establish the 50 percent density points (see also Note).

NOTE

An alternative technique is to use a thimble ionisation chamber to plot the X-ray field instead of film.

(4) Measure the distances (in cm) between 50 percent points along the G-T and A-B axes on the film. Check that the readout of field size on the VDU display agrees with the measurement. If not, adjust the calibration of the data readout voltages as described in Chapter 4.

(5) Open the diaphragms out then close them again to the 30 cm indications. Expose a second film, suitably marked, and check that the field size agrees with the readout on the VDU display to within 2 mm. If not, repeat (4) until the required agreement is obtained.

(6) Repeat (5) for field sizes of 15 cm x 15 cm and 3 cm x 3 cm. Make further adjustments to the calibration, if necessary, to optimise the agreement between X-ray field size and displayed field size.

(7) Check that the optical field agrees with the X-ray field to within 2 mm at all three field sizes. If necessary, adjust the optical trimmers and field-defining lamp to obtain this agreement.

4.3 FIELD-DEFINING LAMP ADJUSTMENTS

The field-defining lamp assembly (Fig. 7) incorporates various mechanically-adjustable parts which permit the projected optical field to be set-up so that it appears to come from the target. The optical field will then be the same as the X-ray field for all positions of the diaphragms.

All the adjustments have been made in the factory prior to installation, and the customer is advised not to touch them since the adjustments are inter-dependent and therefore the re-alignment and positioning of the field-defining system is a time-consuming process requiring care and patience.

Nevertheless, if ever the field-defining lamp assembly needs to be dismantled, note the orientation of the graticule in the assembly. It can then be refitted as originally, so that the position of the wedge filter in the field will be correctly indicated.

Also note, with reference to Fig. 7, that the tip of screw 'B' is in contact with the face of the clamp, thus providing an index to the original axial position of the body when it is being reassembled.

In general, the only procedures that may have to be carried out are:

- Renewal of the lamp bulb;
- Slight adjustment of the tilt of the mirror mount to bring the image of the crosswires to the isocentre if this image has drifted slightly;
- Focus adjustment, which is easily carried out but only slight adjustment should ever be necessary; a large readjustment would imply serious misalignment.

4.4 RENEWAL OF THE FIELD-DEFINING LAMP BULB

Proceed as follows:

(1) Remove the Radiation Head cover.

(2) Using a screw-driver, remove the two M3 slotted pan head screws securing the lampholder to the bulb mount (see Fig. 7). Withdraw the lampholder and bulb from the bulb mount.

(3) Note how the lamp bulb is seated in its socket on the lampholder; then remove and discard the lamp bulb.

(4) Fit a new tungsten halogen lamp (50W, 12V) into the lampholder ensuring that it is seated properly in its socket as noted in step (3).

CAUTION

Take care not to handle the lamp by its glass envelope or it will be damaged in use. Clean off any fingermarks with Ligroin spirit.

(5) Refit the lampholder to the bulb mount and secure with the two M3 slotted pan-head screws removed in step (2).

(6) Check the operation of the field-defining lamp. If the illumination of the field is uneven or dim, re-adjust the lamp bulb in its socket to achieve maximum brightness and even illumination.

(7) Refit the Radiation Head cover.

4.5 ADJUSTMENT OF PROJECTED IMAGE OF CROSSWIRES

Check the projected image of the crosswires as follows:

(1) Set the treatment table-top to the isocentre. Fix a sheet of graph paper, centred on this point, to the table top surface.

(2) Mark the intersection of the crosswires on the graph paper. Rotate the Radiation Head through 90 degrees and again mark the intersection of the crosswires. Repeat this procedure for the other two cardinal points at 90 degree intervals.

(3) Join the first mark to the third and the second to the fourth. The point of intersection determines the isocentre which is the correct position for the crosswires to intersect. If the marks are more than 1 mm apart the projection of the crosswires will need adjusting.

Adjust the projected image of the crosswires as follows:

(4) Remove the Radiation Head cover.

(5) For access to the following adjustments on the Field Defining Assembly, take out the four M5 screws, (Fig. 7, inset diagram) and remove the brackets carrying the lead shield.

(6) Adjust the tilt of the mirror mount with respect to the mirror mount bracket by slightly slackening the mirror locking screw (M3) hex. head, Fig. 7), then adjusting one or other of the three mirror adjusting screws and retightening the locking screw, to bring the intersection of the crosswires over the isocentre marked on the graph paper.

(7) Rotate the radiation head through 360 degrees and check that the projected crosswire intersection remains within a circle of 1mm diameter. If not, repeat the adjustment procedure.

(8) Refit the brackets carrying the lead shield.

(9) Refit the Radiation Head cover.

4.5.1 Focusing the Projected Image of the Crosswires

If it is necessary to bring the image of the crosswires into sharper focus, loosen the focus locking ring and shift the focus lens (Fig. 7) up or down until the required sharpness of the image is obtained; then tighten the focus locking ring.

CAUTION

Refrain from shifting the focus lens too much since a large adjustment will mismatch the optical field with respect to the X-ray field.

4.6 OPTICAL DISTANCE METER

The setting-up of the Distance Meter is not simple, due to the interaction of the mechanical movements involved, and is preferably carried out by an experienced person at the time of installation. It is unlikely that the original setting will change in service. If the calibration is found to be incorrect, the most probable cause is that the Distance Meter assembly has received a severe knock, in which case resetting the pivot angle may be all that is required. Retighten the fixing screws after completing each adjustment.

4.6.1 Scale Alignment

To align the projected light scale with the image of the longitudinal crosswire:

(1) Set the radiation head (diaphragms system) to 0°.

(2) Position the surface of the treatment table at the isocentre and place a sheet of white paper on it, directly below the head.

(3) Switch on the FIELD-DEFINING and DISTANCE METER push-buttons at the Movements Controller.

(4) Loosen the two grub screws securing the body of the Distance Meter in its carrier and rotate the body until the scale line is parallel to the longitudinal crosswire. Centralise the collar of the body axially in the carrier when the correct rotational position has been found.

(5) Remove the two-piece cover and loosen the two bolts in the base plate of the touchguard assembly. Move the assembly, within the limits of its over-size fixing holes, to adjust the scale sideways until its edge is coincident with the longitudinal crosswire.

Try to leave the mounting with equal amounts of possible movement at right-angles to that just used, for later axial movement of the scale during calibration.

4.6.2 Scale Calibration

To set up the scale calibration:

(1) Position the treatment table with its surface precisely at the isocentre.

(2) Slacken the two screws in the touchguard arms and pivot the Distance Meter assembly until the 100 cm indication ±1 mm occurs at the intersection with the horizontal crosswire.

(3) Simulate a decrease in SSD by supporting a sheet of paper in the horizontal plane at 15 cm above the isocentre. The scale indication should read 85 cm ±3 mm.

(4) Lower the table by 35 cm from the isocentre. The scale indication at the table surface should read 135 cm ±3 mm.

(5) If the readings are high or low, alter the longitudinal position of the scale in the required direction by movement of the complete touchguard assembly, as in 4.6.1 step (5), then reset the angle of the Distance Meter to bring the 100 cm indication to the intersection of the crosswires. Repeat this procedure, as necessary, until the calibration is correct.

4.6.3 Renewal of the Distance Meter Lamp Bulb

Access to the lamp bulb is obtained by removing the two screws in the base of the Distance Meter and withdrawing the base plate, complete with its lampholder. The two-pin lamp is a push fit in the holder.

4.7 AUTO-WEDGE FILTER ASSEMBLY

Remove the radiation head cover and collimator cover for access to the auto-wedge filter assembly. Withdrawal of the assembly gives access to the head interior, including the two interior illumination lamps and the Mylar mirror. To renew the mirror it is additionally necessary to remove the steel plate carrying a lead shield and slide the mirror assembly out of the head.

5. REMOVAL OF GANTRY COVERS

Before carrying out maintenance procedures on the Gantry it will be necessary to remove some or all of the covers to gain access to the equipment. The covers are removed in a particular sequence as described below.

5.1 PREPARATION

Prior to removing covers, which entails positioning the gantry for best access to their fixing points, prepare the working area as follows:

(1) Position the Patient Support System clear of the arc of gantry rotation:

- Rotate P.S.S. turntable to 0°.

- Position table top at 90°, i.e. perpendicular to the G-T axis.

(2) It is also preferable to swing back the MCC and Modulator cabinets for maximum clearance around the gantry. An assistant will be required to support the covers as they are released and to help lift them clear.

5.2 IF A BEAM ABSORBER IS NOT FITTED

The locations of the covers and their fixing points are shown on Fig. 8.

5.2.1 Side Covers

Remove the gantry side covers as follows:

(1) Insert a 5mm A/F Allen key and turn it 90° to release the two latches (A), at the rear top and bottom corners of each side cover.

(2) Pull each side cover rearwards, keeping it vertical, so as to disengage its four dowel pins (C) and free it completely.

5.2.2 Gantry Arm and Other Covers

To remove the gantry arm covers continue as follows.

(1) Remove the upper rear panel:

- Rotate the gantry to 90°.

- Undo the three pan-head, slotted M6 screws, with washers, (B) on the outside of the gantry arm outer (top) cover.

- Undo the two external, counter-sunk slotted head M5 screws (S). Take care not to lose their seating discs.

(2) Remove the radiation head cover:

- Rotate the gantry to 180°.

- Remove the radiation head touchguard by undoing two knurled screws (M) on the ends of the touchguard supports.

- Remove the radiation head cover by extracting six screws (K) attaching it to the accessory ring.

(3) Remove the collimator cover:

This can be done separately, after removing only the radiation head cover.

- It will be found convenient to rotate the gantry to 90 or 270°.

- Undo the innermost pair of wing nuts (L) at the front of the collimator. (The outer pair secure the gantry arm outer cover, see next step).

(4) Remove the gantry arm outer (top) cover:

- Rotate the gantry to 90°.

- Undo two wing nuts (G) at the radiation-head end of the gantry arm inner cover.

In the next operations, an assistant should support the cover as it is freed, and then help lift it clear.

- Undo the two wing nuts (H) attaching the cover to the collimator.

- Undo the two hexagonal M6 nuts and washers (D), at the gun end of the cover.

- The gantry arm outer cover can now be lifted clear.

(5) Remove the gantry balance weight cover:

- Rotate the gantry to 180°.

- Undo the two wing nuts (P), securing the balance weight cover to front cover.

- Undo two M6 cap-head screws with washers (R) at each side, securing cover bracket to balance weight studs.

- The cover may now be removed.

(6) Remove the gantry front cover:

- Have the gantry still positioned at 180°.

- Undo the remaining two wing nuts (N), securing the front cover to the gantry arm inner cover.

(7) Remove the gantry arm inner cover:

It will facilitate refitting the gantry arm inner cover if the original fixing positions of its mounting brackets, which have slotted holes for adjustment purposes, at positions (E) and (F), are marked beforehand.

- Undo the M6 hexagonal nut and cap-head screw (F) on each side, at target end of the cover.

- Undo the two M6 hexagonal-head screws (E) on each side of the cover, at the gun end.

- The gantry arm inner cover can now be lifted clear.

5.3 IF A BEAM ABSORBER IS FITTED

The locations of the covers and their fixing points are shown on Fig. 9.

5.3.1 Side Covers

Remove the gantry side covers as follows:

(1) Release the two latches (A) at the top and bottom rear corners of each side cover.

(2) Pull each side cover rearwards, keeping it vertical, so as to disengage its three dowel pins (C) and free it completely.

5.3.2 Gantry Arm and Other Covers

To remove the remaining covers, continue as follows:

(1) Remove the upper rear panel:

- Rotate the gantry to 90°.

- Undo the three screws (B) accessible from inside the outer arm cover.

- Undo the two external countersunk screws (S) taking care not to lose their seating discs.

(2) Remove the radiation head cover:

- Rotate the gantry to 180°.

- Remove the radiation head touchguard by undoing the two knurled screws (L) on the ends of the touchguard supports.

- Remove the radiation head cover by extracting the six screws (K) attaching it to the accessory ring.

(3) Remove the collimator cover:

- This can be done separately after removing only the radiation head cover.
- It will be found convenient to rotate the gantry to 90° or 270°.
- Undo the innermost pair of wingnuts (G) at the front of the collimator. (The outer pair of wingnuts secure the gantry outer arm cover - see next step.)

(4) Remove the gantry outer arm (top) cover:

- Rotate the gantry to 90° or 270°.
- Undo the two nuts (D) at the rear of the inner arm cover.
- Undo the two wingnuts (H) attaching the cover to the collimator.
- Undo the two nuts (V) which attach the outer arm cover to the inner arm cover. The outer arm cover can now be lifted clear.

(5) Remove the gantry inner arm and front covers:

NOTE

It will facilitate replacement of the gantry inner arm cover if the original fixing positions of its mounting brackets, which have slotted holes for adjustment purposes, are marked beforehand.

- Rotate the gantry to the 180° position.
- Remove the small panel around the touchguard supports by undoing the two screws (J).
- Undo the two screws/nuts (E) (plus a location screw) on each side which join the slotted angles mounted on the inner arm cover to L-shaped brackets mounted on the gantry structure. Do not disturb the setting of the slotted angles.
- Remove the two screws/nuts (N) attaching the inner arm cover to the front cover.
- Remove the two screws/nuts (W) attaching the inner arm cover to support brackets mounted on the gantry structure. Do not disturb the setting of these brackets - see note above.

- First lower the rear end of the inner arm cover to disengage it from the dowel (M) which protrudes from the front cover, then move the inner arm cover forwards, manoeuvring the front end clear of the touchguard supports and the radiation head.

- Support the front cover whilst removing the two screws/nuts (N) which attach the front cover to the beam absorber frame inner cover.

- Lower the front cover to disengage the dowel (M) which protrudes into the beam absorber frame inner cover, then lift the front cover clear of the gantry.

(6) Remove the beam absorber cover:

- It will not be necessary to remove the beam absorber cover unless it has been damaged.

- Retract the beam absorber and rotate the gantry to the 0° position.

- Undo the two screws (X) to free the front end of the beam absorber touchguard from its flexible mount.

- Undo the four knurled screws (R) to release the touchguard.

- Extend the beam absorber.

- Remove the screw (U) and the two screws (Y) to free the beam absorber cover.

(7) Remove the beam absorber frame inner cover:

- Remove the six screws/nuts (P) (three on each side) which join it to the beam absorber frame outer cover. The screws/nuts are accessible from inside the covers.

(8) Remove the beam absorber frame outer cover:

NOTE

It will facilitate replacement of the frame outer cover if the original fixing positions of its mounting brackets, which have slotted holes for adjustment purposes, are marked beforehand.

- Undo four screws (T) which attach it to four mounting brackets on the frame. Do not disturb the setting of these brackets.

5.4 REPLACEMENT OF COVERS

To replace the covers, reverse the removal procedures. Note the following points:

- When replacing the gantry outer arm cover on beam absorber machines, take care to locate the guides (F) (Fig. 9) along the side joins correctly.

- When replacing the gantry front and arm inner covers, make sure that the dowels (M) (Figs. 8 and 9) are correctly located.

- Ensure that the radiation head cover is correctly oriented. Its mechanical scale indication should correspond with the diaphragms rotation angle displayed by the movements VDU in the treatment room.

- Check that the gantry angle scale on the front cover is correctly oriented. The scale will fit either way up.

6. REMOVAL OF RADIATION HEAD

The radiation head consists of a fixed collimator bolted to the end of the gantry arm, and a rotatable diaphragm system that attaches to the collimator.

6.1 PREPARATION

Before removing the radiation head:

(1) Remove the treatment table from the P.S.S.

(2) Pedestal type P.S.S. - rotate the turntable so that the pedestal is in the 0 degree position.

Ram type P.S.S. - fully retract the ram and cover the hole in the floor.

CAUTION

The gantry must not be rotated after removal of the radiation head or else damage could result due to the severe out of balance condition. To prevent rotation, insert the gantry locking pin (see text 2.3) and remove Thyristor Power Board PWB62-E.

6.2 REMOVAL OF THE DIAPHRAGM SYSTEM

Weight : 300 kg

Equipment required:

- 4 mm A/F hexagonal socket wrench (Allen key).

- 6 mm A/F hexagonal socket wrench (Allen key).
- 8 mm A/F hexagonal socket wrench (Allen key).
- Screwdrivers: 3 mm blade, 6 mm blade.
- Lifting tackle: hoist, rope slings.

To remove the diaphragm system:

(1) Ensure that the treatment table is clear of the lifting area.

(2) Rotate the Gantry to the 180 degrees position, i.e. with the radiation head pointing vertically upwards.

(3) Remove the touchguard, radiation head cover and collimator cover.

(4) Ensure that the SUPPLIES switch on the engineers' panel of the TCC is set to OFF.

(5) Disconnect PL53A on the side of the diaphragm system. Lay the 50-way free socket and its two cables clear of the head.

(6) To gain access to head fixing screws on the head ring, remove two lead shield-bars (mounted near the head ring) by unscrewing two M5 screws from each bar using the 4mm Allen key. Recover four plain washers.

(7) Remove the ring of six M10 hexagonal socket cap-head screws using the 8 mm Allen key, and two M10 hexagonal socket countersunk-head screws using the 6 mm Allen key; (these screws secure the head ring of the diaphragm system to the collimator bearing). Recover six plain washers and six spring washers.

(8) Pass a rope sling round the pair of lifting hooks mounted at the corners, near the accessory ring, at one side of the head and another rope sling round the pair of hooks on the other side of the head; pick up the two loops with a hoist. Ensure that the rope loops are evenly tensioned to obtain a straight lift.

(9) Ensure that the 50-way free socket and its two cables are clear of the rotatable diaphragm system, then lift the rotatable diaphragm system clear of the collimator. Swing it away from the Gantry arm and lower it gently to the floor.

6.3 REPLACEMENT OF THE DIAPHRAGM SYSTEM

To replace the diaphragm system:

(1) Lift the diaphragm system as described in step (8) of 6.2 and position it over the collimator.

(2) Rotate the diaphragm system about the vertical axis to position the side containing the 50-way fixed plug PL53-A with respect to the 50-way free socket on the collimator.

(3) Ensure that this free socket and its two cables are clear of the collimator surface; then lower the diaphragm system until it is just clear of the collimator.

(4) Align the fixing holes in the head ring with those in the collimator bearing; then insert the ring of six M10 hexagonal socket cap-head screws, together with a plain washer and a spring washer for each screw, and the two M10 hexagonal socket countersunk-head screws.

(5) Fully lower the diaphragm system and remove the lifting tackle.

(6) Tighten the eight M10 socket screws, using the 8 mm Allen key for the cap-head screws, and the 6 mm Allen key for the countersunk-head screws.

(7) Replace the two lead shield-bars using the two M5 hexagonal socket cap-head screws for each bar together with a plain washer for each screw. Tighten the screws using the 4 mm Allen key.

(8) Connect the 50-way free socket to the 50-way fixed plug PL53-A.

(9) Replace the radiation head cover.

6.4 REMOVAL OF THE COLLIMATOR

Weight : 140 kg

Additional equipment required:

- 10 mm A/F hexagonal socket wrench (Allen key)
- Lifting eyes (2 off) and fixing screws.
- Punch and hammer (for 10 mm dowels).

To remove the collimator:

(1) Remove the covers from the radiation head and collimator as described in text 5.3.

(2) Check that the P.S.S. turntable area is clear, then rotate the gantry to the 180 degree position. Remove the diaphragm system as described in text 6.2.

(3) Disconnect PL40A, adjacent to the pre-amplifier box on the gantry arm, and also the ten sub-minature coaxial connectors PL-a to f, h to k, and y from the gantry pre-amplifier.

(4) Release the dowelled cover fixing plates from the collimator plate. Remove six remaining M12 Allen screws from the collimator mounting plate. Remove the two locating dowel pins by tapping them out using a punch.

(5) Pass a rope sling through each of the two lifting rings on the collimator and pick up the two slings with a hoist. Lift the collimator clear of the box-section housing the bending chamber and target assembly.

(6) During lift off, check if any shims are placed under the collimator mounting plate and note their positions for subsequent replacement. Manoeuvre the collimator clear of the gantry arm, and lower it onto wooden blocks on the floor : the blocks are to prevent the projecting end of the collimator from touching the floor.

6.5 REPLACEMENT OF COLLIMATOR

(1) Position the collimator over the box on the gantry arm, ensuring that any shims required are in position. Carefully lower the collimator, taking care to align the fixing holes and not to trap any cableforms when bedding it down.

(2) Insert the locating dowel pins and tap them home.

(3) Insert six M12 Allen screws; reassemble and realign the two cover fixing plates (text 6.4 (4)), then tighten all eight Allen screws.

(4) Reconnect PL40-A to SK40-A and the ten sub-miniature co-axial connectors to the gantry preamplifier.

(5) Replace the collimator cover.

(6) Replace the diaphragm system as described in text 6.3.

(7) Relace the radiation head cover.

NOTE

Provided that sufficiently strong slings and lifting gear are used, the diaphragm system and collimator together can be removed from the gantry arm. The procedure in text 6.4 should be followed, except that the slings should be attached to the hooks on the diaphragm system instead of the lifting rings. (Total weight : approximately 440 kg).

7. GANTRY DISTRIBUTION PANEL

- Circuit diagram 4513 326 3000, Gp. 130, Sht. 1

This panel, carrying three multi-way terminal strips (TS1, 2 and 3), and sixteen coaxial connectors SK34-A to T (less G, I, O and Q) is mounted over the area occupied by the Focus 2 Power Supply (see Fig. 3).

Access to the front of the Focus 2 Power Supply is obtained by loosening the two hexagonal-head screws at each side of the Distribution Panel and lifting the coaxial connectors end of the panel outwards from its slotted fixing holes.

* * * * *

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1. INTRODUCTION

The interlock system consists of a comprehensive arrangement of relays, switches and transistor-controlled circuits, which ensure correct operating conditions at all times. The interlocks fall into two main categories, namely, machine interlocks and treatment interlocks; however, the two areas are not completely independent. Machine interlocks prevent the equipment being operated unless it and its services are functioning properly; treatment interlocks ensure that treatment parameters are correctly selected and confirmed, and that the necessary precautions concerning patient and operator safety are taken, before treatment is given.

To comply with the requirements of the UK Health and Safety Executive (HSE), machines installed in the UK have additional interlocks which ensure that HT cannot be switched on unless the modulator door is closed and the modulator pannier is locked against the gantry support frame. The descriptions which follow apply to all machines uless stated otherwise.

Interlock circuits are shown on the following diagrams:

- Interlocks and Systems : 4513 329 0010, Gp.130, Sht. 1 to 4
- MCC - Interconnections : 4513 329 6000, Gp.130, Sht. 1 & 2
- Beam Absorber Conversion Kit : 4513 329 0730, Gp.130, Sht. 2
- HSE Switch Kit (UK only) : 4513 329 0760, Gp.130, Sht. 1

2. SUPPLIES SWITCH-ON

When the Linac is switched off, the following parts of the system remain connected to the a.c. mains supply via their circuit breakers:

CB1 - 24 volts a.c. interlocks supply transformer T1 in the MCC, Level 4

CB1 - Battery charging transformer T1 in the TCC, Mains Distribution Unit

CB2 - Vacuum Ion Pump power supply in the Gantry

CB3 - Refrigerator in the Water Cooler

However, the rest of the machine is isolated from the mains supply by the Supplies On contactor CON60-A. When the SUPPLIES switch on the engineer's panel is operated, this contactor is energised and held so by its hold contacts, in

series with contacts of RL60J and RL60K and the client's Emergency Off switch where fitted. T1, RL60J and RL60K are each energised from a separate phase of the input mains (RL60J and RL60K via the water cooler circuit breaker CB3). Thus switch-on is impossible unless CB3 is on and all 3 mains phases are present. Power is then made available to all parts of the machine: the Water Cooler pump is switched on and 24 volts a.c. from T1 is fed to the main interlock circuits of the machine which are described below.

3. MACHINE INTERLOCKS

3.1 INTRODUCTION

Most of the machine interlocks are involved with completing a 24 volts a.c. circuit to the Gun On relay RL60-A and the Focus Start relay RL60-B in the MCC, and the subsequent energising of the H.T. Power Supply in the Gantry Support Frame Assembly.

3.2 WATER COOLING INTERLOCKS

Each of the six water cooling circuits in the Linac includes a flow switch that detects when the flow rate falls below a safe level. The six switches have their normally-open and common contacts connected in series; these contacts are closed when the flow rate is correct. All six normally-closed contacts are connected in parallel to the WATER FLOW indicator on the engineer's panel of the TCC. Thus, if one of the flow switches is released because of insufficient water flow, the series circuit is broken and the warning lamp is lit. The six switches are allocated as follows:

SG : Focus coils

SH : Magnetron

SJ : Target

SK : Waveguide and a.f.c. block

SL : Isolator and pulse transformer

SE : H.T. transformer

Next in the interlock chain is the water temperature relay in the Water Cooler. This remains energised as long as the cooling water temperature is within preset limits, thereby closing the interlock circuit. If the water temperature becomes excessive, the relay is de-energised, breaking the interlock circuit and causing the WATER TEMP indicator on the TCC to light up. For details see Chapter 11 : Water Cooling System.

3.3 MAGNETRON FILAMENT SUPPLY INTERLOCK

The magnetron filament supply interlock prevents operation of the magnetron at low p.r.f. rates unless its cathode is heated sufficiently. An undercurrent trip circuit at Level 1 of the MCC detects when the magnetron filament current

is too low, and de-energises the Mag. Fil. Fault relay RL61-C as a result. A changeover contact set of this relay breaks the interlock circuit and lights the MAG. FIL. FAULT indicator on the TCC when a fault occurs. For details, see Chapter 7 : Microwave System.

3.4 TIMER

When the machine is first switched on, a 5-minute warm-up delay is imposed before the electron gun, focus supplies or H.T. can be switched on. The timer for this delay is situated at Level 4 of the MCC. During the delay, the TIMER indicator on the TCC remains lit. After the delay has elapsed, the timer motor is disconnected, the indicator on the engineer's panel of the TCC is extinguished and the interlock circuit is closed.

3.5 VACUUM INTERLOCKS

Trip circuits are actuated at two levels of vacuum pressure, nominally 10^{-4} torr and 10^{-5} torr. When the pressure rises above 2×10^{-5} torr, p.r.f. is inhibited thereby interrupting Linac output but maintaining the H.T. supply. If the pressure rises above 2×10^{-4} torr, however, relay RL76-C in the TCC is de-energised and the main interlock circuit is broken. In either situation, the VACUUM FAULT indicator on the engineer's panel of the TCC lights up. The Vacuum 10^{-5} interlock may be by-passed, with discretion, by use of the VACUUM OVERRIDE switch on the engineer's panel. For details, see Chapter 8 : Vacuum System.

3.6 GUN SWITCH-ON

When all the interlocks so far described are complete, the electron gun can be switched on by energising the Gun On relay, RL60-A. This action takes place automatically if the STANDBY/PREPARATORY key-switch on the TCC is set to PREPARATORY, or by operation of the GUN ON/OFF switch on the engineer's panel if the key-switch is set to STANDBY. Until H.T. is switched on, the gun filament current remains at a standby level of approximately 5 amperes. For details see Chapter 9 : Beam Control.

3.7 WAVEGUIDE PRESSURE/R.F. LOAD TEMPERATURE INTERLOCK

Two associated interlocks are involved in energising the Guide Fault relay RL76-B (Sheet 2 of circuit diagram). The rectangular waveguide sections at the input to and output from the accelerator waveguide are air-pressurised to prevent arcing between the waveguide walls. If the pressure falls below a preset level, switch SN in the Gantry is operated, breaking the +24 volts supply to RL76-B. Similarly, if the r.f. load becomes overheated, switch SM is operated, breaking the supply to RL76-B. When the relay is de-energised, the main interlock circuit is broken by one set of contacts, and the GUIDE FAULT indicator on the engineer's panel of the TCC is lit up via a second set of contacts.

3.8 ROOM INTERLOCKS

Room interlocks (Sheet 2 of circuit diagram) include not only the treatment room door switches, but also the contacts of relay RL89-K in the Patient Support

System. These contacts are closed when the PSS table is locked; then +24 volts is applied to the room door switches. When the room door switches are closed, the Room Interlocks relay RL76-A is energised thereby closing a contact in the main interlock chain. The ROOM INT. COMP. indicator lights up on the engineer's panel of the TCC also. Other contacts of RL76-A operate in the optional Auto set-up system.

UK machines are fitted with the "HSE Switch Kit" (see 4513 329 0760, Gp.130-1) whereby the room interlocks chain also includes contacts of switches SWH and SWJ, operated by the modulator door and pannier respectively. Thus RL76-A cannot energise unless the modulator door is closed and the pannier is secured against the gantry support frame.

The HSE Switch Kit also provides an additional contactor 60-E controlling the 3-phase mains supply to the HT transformer. Contactor 60-E is energised from the switched 24V a.c. supply by an interlock chain which comprises three positive action type switches. Referring to the above diagram:

- SWE is a captive key type switch that combines the functions of door lock and safety switch. An 'operator' mounted on the modulator cabinet door engages with a 'lock', containing the switch, inside the cabinet. A 4mm Allen key is required to turn the operator between the door locked-switch closed and the door open-switch safe positions. A special enclosure screw key (Drg. No. 4513 329 0769) is needed to gain access to the interior of the lock for wiring purposes.

- SWF is mounted on the gantry support frame and has a rotary actuator. The actuator is permanently coupled to the modulator pannier via a 'slider-crank' mechanism. The switch opens when the pannier is swung away from the gantry support frame.

- The treatment room door switch is supplied by the customer.

On machines fitted with the primary beam absorber, the room interlocks circuit includes contacts of switches SF and SD (see 4513 329 0730 Gp. 130-2). These switches operate to break the interlocks chain unless one or other of the following conditions is true:

- Gantry at an angle (e.g. 0°) where use of the beam absorber is not necessary.

- Beam absorber extended with gantry at an angle where use of the beam absorber is necessary.

BEAM STOP warning indicators on the movements controller and the engineer's panel of the TCC will illuminate if the above conditions are not met.

3.9 'STANDBY/PREPARATORY' SWITCH

The Room Interlocks signal is connected via contacts 6-7 of RL76-A to one of two parallel circuits, depending on the setting of the STANDBY/ PREPARATORY key-operated switch on the TCC. With the switch set to STANDBY, the signal is applied to the H.T. switch on the engineer's panel. When the switch is set to

PREPARATORY, the signal is fed to the first of four sets of contacts concerned with treatment interlocks (see 4. TREATMENT INTERLOCKS).

3.10 FOCUS AND H.T. SWITCH-ON

With the key-switch on the TCC turned to the STANDBY position, the Focus Power Supplies are switched on by operating the H.T. switch on the engineer's panel. When the H.T. switch is held in the START position, the H.T. ON indicator lamp lights and the Focus Start relay RL60-B at Level 4 of the MCC is energised so that 3-phase power is fed to the Focus Power Supplies via CB5 and current limiting resistors (see also 4513 329 6000, Gp.130-1). Another contact of the Focus Start relay energises the Focus On contactor CON60-B whose contacts by-pass the Focus Start relay contacts and surge-limiting resistors almost immediately).

The 24 volts a.c. signal that energises the Focus On contactor also feeds via a contact of the H.T. Overload relay RL61-D to the H.T. Start relay RL60-C. This relay operates in a similar manner to the Focus Start relay, by applying the 3-phase mains to the H.T. Power Supply via CB6 and current-limiting resistors, and at the same time energising the H.T. On contactor CON60-C which by-passes the relay contacts and surge-limiting resistors almost immediately. An auxiliary contact of CON60-C (see 4513 329 0010, Gp.130-2) energises the H.T. Hold relay RL76-D to complete a hold-on circuit for the H.T. switch (and H.T. ON indicator lamp) on the engineer's panel, which can now be released to its ON position.

3.11 H.T. OVERLOAD INTERLOCK

After H.T. has been switched on, the mean current supplied by the H.T. Power Supply is continuously monitored by a circuit at Level 1 of the MCC (see Sheet 2 of the circuit diagram). This circuit controls the Magnetron Filament Power Supply so as to obtain the correct filament current according to the p.r.f. selected. It also detects when an H.T. overload occurs and in such circumstances de-energises the H.T. Overload relay RL61-D. This breaks the 24 volts a.c. circuit to the H.T. Start relay and H.T. On contactor so that H.T. is switched off. The H.T. OVERLOAD indicator on the engineer's panel is also illuminated and the VAC 10^{-4} relay RL76-C in the TCC is de-energised, thus breaking the treatment interlocks chain. For details see Chapter 6 : Modulator System.

3.12 P.R.F. INHIBIT INTERLOCKS

Certain fault conditions cause the Linac radiation output to cease but do not switch off H.T. Instead, the P.R.F. Generator output is inhibited so that the magnetron and electron gun are not pulsed. Circumstances are as follows:

- Reverse diode overload (see Chapter 6 - Modulator System);
- Focus fault (see Chapter 9 - Beam Control);
- Vacuum fault (see Chapter 8 - Vacuum System).

P.R.F. is also inhibited at the termination of irradiation or if the P.R.F. selector on the engineer's panel is set to OFF when the machine is operating in the standby mode.

3.13 CONTROL READY STATE

Provided that the room interlocks circuit is complete, when the key-switch on the TCC is turned to the PREPARATORY position, the Control Ready relay RL76-E is energised. Its contacts then operate to signal to the TCC (at pin 5b of PWB76-P) that the state of machine readiness has been reached for a treatment to be given.

4. TREATMENT INTERLOCKS

4.1 FAULT RESET

With the key-switch on the TCC in the PREPARATORY position, it is first necessary to operate the FAULT RESET switch on the engineer's panel for 2-3 seconds to clear any FAULT indication displayed due to the latching action of the trip circuits when the machine is initially brought into operation.

4.2 TREATMENT INTERLOCK RELAYS

Three sets of treatment-termination relay contacts, Dose 1, Dose 2 and Time, form part of the H.T. interlock circuit when the Standby Preparatory key-switch is in the PREPARATORY position. The further conditions which have to be met in order to close the relay contacts are as follows:

NOTE

> The contacts are described in the order in which they are closed, not the order in which they are connected in the circuit.

- Systems Ready interlocks are complete (see Chapter 10 : Movements Control System), so providing a +24 volts supply for the circuit of Treatment Start relay RL76-F.

- All fault, manual and moving beam therapy termination conditions have been cleared (see Chapter 5 : Treatment Control System).

- Selection of a wedge dose or zero wedge dose has been made at the keyboard of the TCT (see text 5).

- If a wedge dose is to be given, the diaphragms have been set to a field size not greater than 20 cm (X-field) by 25 cm (Y-field).

- An irradiation dose and time have been entered at the keyboard of the TCT (see Chapter 5 : Treatment Control System).

- The correct signals are present at the external Termination, Interrupt and Ready terminals, if applicable.

- Stationary or moving beam technique has been selected; in the latter case, with the gantry at the required starting angle (arc) compatible with the direction of rotation and Start/Stop Angles selected.

When all of these conditions have been satisfied, READY TO START is displayed at the TCT and the circuit of the Treatment Start relay RL76-F is completed to 0V via pin 6b of PWB76-P. The relay is then energised when the treatment START push-button is pressed.

4.3 MOVEMENTS 'SYSTEMS READY'

The 24 volts d.c. power source used for the treatment start interlocks is located in the Movements Control circuit at Level 2 of the MCC (see 4513 326 0010, Gp.130, Sheet 3), and consists of a mains step-down transformer T1 with a full-wave rectifier fed from the secondary. The mains supply to T1 is via Supplies On contactor CON60-A and circuit breaker CB10, and is dependent on the Movements interlocks being complete (see text 7) so that CON60-D contacts are closed. Under these conditions the SYSTEMS READY indicator on the Movements Controller is illuminated and 24 volts d.c. is available at the treatment Start switch controlling Treatment Start relay RL76-F. This voltage also acts as an 'auto enable' signal to the TCC (PWB76-B and C in parallel and PWB76-P) when the optional Assisted Set-up system is fitted.

4.4 TREATMENT 'READY TO START'

Pressing the treatment START push-button on the TCT energises the Treatment Start relay RL76-F (see Fig. 1). Its contacts complete the treatment section of the H.T. interlock chain to energise the Focus Start relay RL60-B and illuminate the H.T. ON indicator on the engineer's panel. Consequently, the Focus and H.T. switch-on sequence takes place as described above for Standby operation (see 3.10). Another contact of relay RL76-F by-passes the treatment START switch to hold the relay energised when the push-button is released.

4.5 INTERRUPTION AND TERMINATION OF IRRADIATION

The H.T. interlock circuit is broken if one of the four relay contacts (Dose 1, Dose 2, Time and Treatment Start) goes open-circuit. In the case of the Treatment Start relay, this interrupts irradiation and the treatment can be continued, after the cause has been removed, by pressing the START push-button again. In the case of the other relays, however, termination of irradiation takes place, and the resetting procedure and selection and confirmation of treatment parameters has to be carried out before H.T. can be switched on again. Circumstances in which each of the four relays is de-energised are as follows:

- Dose 1 relay : (1) Normal termination when the set dose has been delivered.

  (2) Normal termination when the Gantry reaches the stop angle during arc therapy.

(3) Fault termination because of a flatness, power supply, dose-rate or arc therapy fault, etc. (see Vol. 1, Chap. 2).

(4) Deliberate manual termination by means of the TERMINATE push-button on the TCT or an external termination facility where fitted.

- Dose 2 relay : Termination after failure of Dose Channel 1, when the set dose plus 20 units have been delivered.

- Time relay : Termination after both Dose Channels have failed when the elapsed time equals the set time.

- Treatment Start relay : (1) Deliberate manual termination by means of the TERMINATE push-button on the TCT or an external termination facility where fitted.

(2) Emergency 'Stop Motors' push-button on the Movements Controller (or PSS) has been pressed, or a Gantry Limit 2 switch has been overridden, thus disconnecting the Systems Ready interlock (RL60-F, CON60-D action).

(3) Touchguard actuated by an obstacle causing Gantry rotation to cease (RL62-K action).

(4) Room Door or PSS Table Locked interlock is broken (RL76-A, hence RL76-E, action).

(5) Waveguide pressure or R.F. Load overtemperature fault (RL76-B, hence RL76-E, action).

5. WEDGE FILTER INTERLOCKS

- Gantry circuit diagram : 4513 326 3000, Gp. 130, Sht. 2

Signals from PWB76-P (24V I/O) in the TCC control the energising of RLA in the Autowedge assembly and hence control the movement of the motorised wedge filter (Autowedge) in or out of the radiation beam. Switches SC (Wedge IN) and SA (Wedge Out) in the Autowedge assembly operate at the two limits of the drive mechanism to stop the movement and to confirm the condition to the TCC.

When the Autowedge facility is required, RLA is energised and the wedge moves into the head until switch SC stops further movement. A wedge dose is then enabled provided that the field-defining diaphragms are set for a field size not greater than 20 cm (X-field) by 25 cm (Y-field), i.e. the limiting size for a wedged field.

6. ARC THERAPY : P.R.F. SELECTION INTERLOCK

Outputs from pins 7-B and 8-B of PWB76-P in the TCC select a p.r.f. in accordance with the degrees of Gantry rotation per unit dose computed by the TCC, so that the Gantry is not required to rotate at excessive speed during arc therapy (see Chapter 5).

7. GANTRY MOVEMENTS INTERLOCKS

- 4513 329 0010, Gp.130, Sheet 3

The control system for the gantry rotation, radiation head rotation and diaphragms aperture control is fully described in Chapter 10. Normal operation is dependent, however, on the completion of the basic movements safety interlocks described below. They govern the supply of power to the 'movements enable' switch on the Movements Controller, to the clutch solenoid for the gantry motor drive, and to the Treatment Start relay circuit as already described above.

7.1 STOP MOTORS INTERLOCK

An important feature of the movements interlocks is the emergency 'Stop Motors' interlock. Relay RL60-F (Stop Motors) is energised by the +24 volts supply routed via the following normally-closed contacts:

- STOP MOTORS push-button on the Movements Controller;
- TERMINATE push-button on the TCT;
- Gantry Limit 2 switches (CW and CCW);
- STOP MOTORS push-button on the PSS;
- Patient Support System limit switches.

If any of these contacts is open, RL60-F is de-energised. Thus contactor CON60-D (Stop Motors) is de-energised and disconnects the a.c. mains supply from the movements system, thereby rendering all motors inoperative.

Normal operation is restored by de-latching the operated STOP MOTORS switch and pressing the STOP MOTOR RESET push-button on the Movements Controller. Its contacts then by-pass the relay contacts de-energising RL60-F so that, providing the remainder of the interlock chain is complete, Stop Motors relay RL60-F and hence contactor CON60-D are re-energised. It follows that each time the Linac is initially switched on, the movements interlock system must be re-energised by pressing the STOP MOTORS RESET push-button before any movement can be operated.

7.2 LIMITS OF ROTATION

If the rotation of the Gantry causes it to overrun its appropriate Limit 1 switch, the Limit 2 switch is actuated and breaks the +24 volts supply to relay RL60-F (Stop Motors). Because the Gantry Drive motor is thereby rendered inoperative, the motor must be rotated by hand out of this condition until the Limit 2 switch is no longer actuated. the reason why the Limit 1 switch was overridden must be investigated at once.

7.3 TOUCHGUARD AND SYSTEMS READY INTERLOCKS

The 'Touchguard' interlock chain is in series with the 'Stop Motors' chain, and includes Shadow Tray interlock switches SL 'present', SK 'Locked'. Thus, if either interlock chain is broken touchguard relay RL62-K and the clutch of the Gantry drive motor are de-energised. Relay RL62-K contacts then operate to:

(a) Disconnect the +24 volts System Ready interlock so that the movements Systems Ready and treatment Ready to Start conditions are inhibited;

(b) Inhibit the logic circuit of the Gantry Motor Control board;

(c) Light the TOUCHGUARD warning lamp in the push-button on the Movements Controller.

In the case of the touchguard meeting an obstruction, pressing the illuminated TOUCHGUARD push-button overrides the touchguard interlock switches and enables the Gantry to be driven clear of the obstruction.

When a beam absorber is fitted, the above touchguard chain includes the four touchguard switches on the beam absorber. If either the radiation head or the beam absorber touchguard switches operate, beam absorber motion in the extend direction is inhibited but retraction is still possible. The Movements Controller TOUCHGUARD push-button overrides the beam absorber touchguard, enabling beam absorber motion in both directions.

8. MAINTENANCE INFORMATION

8.1 MACHINE INTERLOCK CHECKS

The functions of the machine interlock circuits are checked as follows:

(1) Check that all ten circuit breakers at Level 4 of the MCC are on.

NOTE

The checks in steps (2) to (8) below utilise the TIMER indicator on the engineer's control panel of the TCT to prove continuity through the first part of the interlock circuit.

(2) Switch the STANDBY/PREPARATORY key-switch to STANDBY. Switch the SUPPLIES switch on the engineer's panel to START then release it to

the ON position. The TIMER indicator on the engineer's panel shall then light (Supplies On contactor CON60-A energised), at which point, start timing the period for the indicator to extinguish. Check that it is not possible to switch on H.T. during the time delay period, which shall be 5 - 6 minutes.

(3) Initial lighting of the Timer indicator in the previous check signifies that the Supplies On contactor CON60-A has been energised. If it is not, check that the 24 volts a.c. interlock supply is present by pressing the DIM LIGHTS or DISTANCE METER push-buttons on the Movements Controller, whose indicator lamps are connected across the supply.

(4) Switch off the Water Cooler circuit breaker CB3, at Level 4 of the MCC. Check that the WATER FLOW indicator on the engineer's panel is lit and that the TIMER light is out.

(5) Switch on the Water Cooler circuit breaker and check that the WATER FLOW indicator goes out after a few seconds and the TIMER indicator lights up again.

(6) Adjust the over-temperature thermostat in the Water Cooler to a setting 5°C below the control thermostat setting, thereby simulating an over-temperature condition. Check that the WATER TEMP indicator on the engineer's panel is lit and the TIMER light is out.

(7) Readjust the thermostat to its original setting (5°C above the control setting) and check that the WATER TEMP indicator is out and the TIMER indicator is lit.

(8) At Level 4 of the MCC, switch off the magnetron filament circuit breaker CB8. Check that the MAG FIL FAULT indicator on the engineer's panel lights up, the TIMER light extinguishes and it is not possible to switch on H.T.

Switch on the magnetron filament circuit breaker and check that the MAG FIL FAULT indicator goes out and the TIMER indicator lights up. Wait for the Timer delay to elapse, at which time the TIMER light will go out.

(9) Operate the Linac for up to about ten minutes in the Standby mode, with H.T. on and the Gun switched off. The R.F. Load Over-temperature thermostat shall operate, as signified by the GUIDE FAULT indicator being extinguished, and it shall not be possible to switch on the H.T.

Do not have the Gun switched off for any longer than necessary.

(10) Confirm that the GUIDE FAULT indicator is extinguished. To check the operation of the associated guide-pressure interlock, reduce the waveguide air pressure by slowly releasing the air via the Air Filter Tap (NOT at the air inlet valve) until the indicator lamp lights; the

GUIDE FAULT indicator should light at a pressure of 1.8 bar (26 psi). Repressurise the waveguide to 2.1 bar (30 psi) afterwards.

(11) To test the Vacuum interlocks, simulate a loss of vacuum as follows:

- Connect a 5 k-ohm potentiometer between 0V (pins 1,22) and -15 volts (pin 21) on Vacuum Monitor board PWB61-L at Level 1 of the MCC. Connect the wiper to input pin 5 or its junction with R1/R2.

- Adjust the potentiometer from zero towards -15 volts until the 10^{-5} trip operates and lights the VACUUM FAULT indicator on the engineer's panel. This should occur at a reading of 2×10^{-5} torr on the vacuum meter plugged in at the MCC. If not, adjust RV3 on PWB61-L to obtain this result.

- Disconnect the test potentiometer from PWB61-L.

(12) Repeat the test of step (11) for the Vacuum 10^{-4} trip, which should operate (as the potentiometer is further advanced towards -15 volts) at a vacuum reading of 2×10^{-4} torr. If necessary, adjust RV2 on PWB61-L to obtain this result.

(13) It should now be possible to switch-on the electron gun. As a functional check, select Standby operation and set the selector switches for the engineer's monitor to GUN-I, then switch-on the gun using the GUN ON/OFF switch on the engineer's panel. Check that the gun standby current level (5 amps. nominal) is indicated.

(14) Check that the ROOM INT COMP indicator on the engineer's panel lights up when the treatment room entry interlock system is operated in the safe condition (see next step for interlock system items).

(15) Check individually, that each of the following causes the ROOM INT COMP indicator to extinguish:

- Treatment room door/barrier open.

- PSS table top not locked

- (UK machines only) Modulator cabinet door open.

- (UK machines only) Modulator pannier open.

- (Beam absorber machines only) Gantry angle such that beam absorber necessary but beam absorber retracted.

(16) (Beam absorber machines only) Check that the BEAM STOP indicator on the engineer's panel and the BEAM ABSORBER push-button on the movements controller both illuminate when the beam absorber is retracted in the presence of a gantry angle which requires use of the beam absorber.

(17) Set the H.T. switch on the engineer's panel to its START position. Check that the H.T. ON indicator on the engineer's panel lights up. Release the switch to the ON position; the indicator should remain on.

(18) Using the engineer's monitor, check that the gun current is now at its normal operational level. Select DOSE RATE and check that the meter is registering an output dose.

(19) Carry out the Reverse Diode Overload check contained in Chapter 6 under 'Maintenance Information'.

(20) At Level 4 of the MCC, switch off the Focus circuit breaker CB5; check that the p.r.f. is inhibited (Chapter 6 - P.R.F. GENERATOR CHECKS) and that the FOCUS FAULT indicator on the engineer's panel is lit.

(21) Check the operation of the H.T. Overload interlock by a simulation method, as detailed in Chapter 6, under 'H.T. Current Monitor Checks'.

(22) Switch off H.T. remove the short circuit.

8.2 TREATMENT INTERLOCKS CHECK

8.2.1. Key-switch Operation

Select TCT Option 0. Check that "STANDBY" is displayed by the VDU when the key-switch is in the STANDBY position and "PREPARATORY" when it is in the PREPARATORY position.

Return the key-switch to STANDBY; all fault indications on the engineer's panel shall be extinguished and the ROOM INT. COMP. indicator shall be illuminated.

8.2.2 Room Door Interlock

Check that when the treatment room door is open or other entrance protection device is actuated, under Standby or Preparatory conditions, the message "DOOR OPEN" is additionally displayed by the VDU and H.T. cannot be switched on.

8.2.3 Treatment : Ready to Start

Set up a stationary, non-wedged, beam treatment at the TCT and check that the message READY TO START can only be obtained when the following conditions have been met:

- The key-switch is in the PREPARATORY position.
- Compatible treatment conditions have been entered at the keyboard and displayed on the VDU.
- A dose and time have been set.

8.2.4 Keyboard Interlock

After starting a treatment, operate the keyboard in an attempt to change the treatment conditions. There should be no interruption or alteration of the treatment program as a result.

8.2.5 Treatment Interrupt

After starting a treatment, press the INTERRUPT push-button. The display of delivered dose shall stop and the message INTERRUPTED - READY TO START shall be displayed. Press the START push-button; the treatment shall recommence.

If an external interruption facility is fitted, operate the external 'interrupt' control and check that irradiation stops etc. as stated above.

8.2.6 Treatment Termination

After starting a treatment, press the TERMINATE push-button. Irradiation shall cease and MANUAL TERMINATION - TERMINATED ABNORMALLY shall be displayed. Check that treatment cannot be restarted by use of the START push-buttton.

If an external termination facility is fitted, operate the external 'terminate' control and check that irradiation ceases etc. as stated above.

8.2.7 Dose Display Hold

(1) After starting a treatment, disconnect the 240 volts a.c. mains supply to the TCC; irradiation shall cease. Note the reading given by the LCD back-up dose-meter on the front panel of the TCC drawer.

(2) Reconnect the mains supply. Operate the TCC keyswitch to OFF and then to STANDBY.

(3) Select TCT Option 3 (PREVIOUS FIELD); the DOSE 2 ACTUAL reading shall be the same as noted in step (1).

8.2.8 Field Symmetry Fault

(1) Select TCT Option 0.

(2) Simulate an X-ray field asymmetry by switching the 2T centring servo system on PWB76-FF to Manual control and offsetting the centring current by RV7, as follows:

Monitor the 2T ERROR current and increase it in steps of about 5 units, pausing for about 5 seconds between steps. The message FLATNESS FAULT shall be displayed on the VDU when the error reading is approximately ±40 units.

(3) Switch the 2T centring servo to AUTO. Start a normal treatment and switch the 2T centring servo to Manual. After 3 seconds approximately, the message FLATNESS FAULT shall be displayed and the treatment automatically terminated.

(4) Switch the 2T centring servo to Manual, restore the centring current to its normal value and switch to AUTO.

8.2.9 Dose 1 Termination

Set a dose of 100 units and a time of 1 minute. Start a treatment and allow normal termination to occur. At termination, the cursor shall be positioned alongside DOSE 1 ACTUAL and the message TERMINATED 1 CORRECTLY displayed.

8.2.10 Dose 2 Termination

Set a dose of 999 units, a time of 9 minutes and start a treatment. Interrupt the treatment at about 10 units from termination of Dose 1.

Remove the Dose 1 signal by disconnecting the coaxial plug PL70-JJ at the connector panel of the TCC.

Restart the treatment. Termination of Dose 2 shall occur at 1019 units and be indicated by the cursor, while the message TERMINATED ABNORMALLY shall be displayed on the VDU.

Reconnect plug PL70-JJ.

8.2.11 Dose 2 Check

Set a dose of 500 units, a time of 1 minute and start a treatment.

After 20 dose units approximately have been delivered, manually terminate the treatment. The message TERMINATED - CHECKING CH. 2 shall be displayed, followed shortly by TERMINATED ABNORMALLY.

8.2.12 Dose Channel Difference Detection : High Dose Level

Set a dose of 999 units, a time of 9 minutes and start a treatment.

Interrupt the treatment at DOSE 1 ACTUAL of 800-819 units.

Remove the Dose 1 signal by disconnecting coaxial plug PL70-JJ on the connector panel of the TCC.

Restart the treatment. Termination of Dose 2 shall occur at 42 units more than the interrupt figure i.e. 5% + 2 units.

8.2.13 Dose Channel Difference Detection : Low Dose Level

(1) Set a dose of 100 units, a time of 1 minute and start a treatment (Dose 1 signal still disconnected).

Termination of Dose 2 channel shall occur at 2 units and the message DOSE CHANNEL DIFFERENCE 2 - TERMINATED ABNORMALLY shall be displayed.

Reconnect plug PL70-JJ.

(2) Repeat the foregoing test but with the Dose 2 signal disconnected at plug PL70-KK on the connector panel of the TCC.

Termination of Dose 1 channel shall occur at 2 units and the message DOSE CHANNEL DIFFERENCE 2 - TERMINATED ABNORMALLY shall be displayed.

Reconnect plug PL70-KK.

8.2.14 Dose Timer

Set a dose of 100 units, a time of 0.2 minute and start a treatment.

Termination shall occur with the cursor positioned against TIME ACTUAL and the message TERMINATED ABNORMALLY shall be displayed.

8.2.15 Dosimetry Fault

Disconnect the signal inputs to both dose channels at PL70-JJ and KK.

Set a dose of 100 units, a time of 1 minute and start a stationary beam treatment. Approximately 7 seconds after the message RADIATION DELAY disappears the treatment shall terminate and the message DOSIMETRY FAULT shall be displayed.

8.2.16 Supply Fault Detector

WARNING

THE USUAL SAFETY PRECAUTIONS MUST BE OBSERVED
WHEN HANDLING THE HIGH VOLTAGE CONNECTIONS.

During irradiation, disconnect the -300 volts supply at coaxial socket SK70-AA on the connector panel of the TCC (see "Warning"). Irradiation shall cease and the message DOSIMETRY FAULT - SUPPLIES shall be displayed (Option 0).

With PL70-AA still disconnected, set-up a treatment. It shall not be possible to start irradiation and the message SUPPLIES shall be displayed by the VDU.

8.2.17 Movements Fault

Set up a normal treatment at the TCT, then switch off the Movements circuit breaker CB10 at Level 4 of the MCC. The status message MOVEMENTS shall be displayed on the VDU.

8.2.18 Excess Dose Rate

Rotate the Gantry to the 180° position. Remove the covers from the radiation head and collimator. Take out the auto-wedge filter assembly. Remove two screws securing the field flattening filter and its adaptor plate to the collimator. Withdraw the filter from the radiation head.

Set up a dose at the TCT, select PRF 1 (50/60Hz) at the TCC and start a treatment.

Increase the p.r.f.; the excess dose rate shall cause immediate termination of treatment and the message EXCESS DOSE RATE shall be displayed.

Replace the field flattening filter et cetera and check that normal operation of the Linac is possible.

8.3 WEDGE FILTER INTERLOCKS

8.3.1 Basic Wedge Filter Interlocks with Stationary Beam

Proceed as follows:

(1) Adjust the X and Y diaphragms by the Movements Controller for a field size of 20 cm X-field, by 25 cm Y-field, or less. Leave the treatment room, completing the door interlocks as necessary.

Set up a stationary-beam treatment with WEDGE DOSE = 0 selected.

The message SETTINGS COMPLETE shall ultimately be obtained, followed by READY TO START when the ENTER key is pressed.

Change the selection to WEDGE DOSE = 100; the prompt message WEDGE IN shall be displayed by the VDU for a few seconds while the wedge is being moved into the field.

(2) Change the treatment settings to:

WEDGE DOSE : 100

TOTAL DOSE : 200

Start the treatment; the VDU shall display the message RADIATION - WEDGE IN.

When the 100 dose units have been delivered, irradiation shall cease (p.r.f. inhibited). The message RADIATION - DELAY shall then be displayed for a few seconds while the wedge filter is withdrawn from the field, after which irradiation shall recommence until normal termination occurs at 200 dose units.

(3) Set up a stationary beam treatment with:

WEDGE DOSE : 100

TOTAL DOSE : 100

Maintain the X and Y diaphragms set for a field size of 20 cm X-field, by 25 cm Y-field, or less.

Start the treatment; the VDU shall display the values of wedge dose and total dose, and the message RADIATION - WEDGE IN.

8.3.2 Wedge Filter/Diaphragms Field Size Interlocks

(4) Check the Wedge Filter/Diaphragms Field Size Interlocks as follows;

- Set up a stationary beam treatment with WEDGE DOSE : 100 selected, concluding with the attainment of READY TO START.

- Enter the treatment room and, using the Movements Controller, adjust the X-field size to 21 cm; the message READY TO START shall disappear, the prompt message DIA/WGE shall be displayed, and it shall not be possible to start the treatment until the X-field size is corrected to 20 cm, or less.

(5) Repeat the foregoing procedure, but with the X-field set to 20 cm and the Y-field set to 26 cm. The same requirement shall be met and it shall not be possible to start treatment until the Y-field size is corrected to 25 cm or less.

8.4 ARC THERAPY INTERLOCKS

CAUTION

Before starting the arc therapy tests, ensure that the Gantry is free to rotate through 360° without meeting any obstruction.

8.4.1 Gantry Movement Interlocks

(1) With the Movements circuit breaker switched on, as normal, the SYSTEMS READY indicator on the Movements Controller shall be illuminated.

(2) Drive the gantry through a full 360° of rotation in each direction in turn; the head touchguard shall not operate by gravity, i.e. the TOUCHGUARD warning lamp in the push-button shall not light at any time.

(3) Actuate the head touchguard while the gantry is rotating in a clockwise direction; movement shall cease instantly and the warning lamp in the TOUCHGUARD push-button shall light.

It shall not be possible to drive the gantry in either direction while the touchguard is actuated.

With the touchguard actuated, press the TOUCHGUARD push-button; it shall now be possible to drive the gantry clear of the obstruction.

(4) Repeat the procedure given in clause (3), but for rotation of the gantry in the counter-clockwise direction.

(5) Operate the STOP MOTORS push-button on the Movements Controller while operating any of the gantry movements. In each instance, the movement in progress shall cease instantly and the SYSTEMS READY indicator on the Movements Controller shall extinguish.

Depress the STOP MOTORS push-button to unlatch it for normal operation again.

Check that it is not possible to operate any gantry movement until the STOP MOTOR RESET push-button has subsequently been pressed to re-energise the movements system.

(6) Drive the Gantry as far as possible c.w. and c.c.w., in turn. The Limit 1 switch shall operate in each instance and halt the movement independently of the maintained position of the thumbwheel control.

8.4.2 Basic Interlocks

(1) Check that the Gantry is at 0°. Set up a treatment at the TCT, using a non-wedged field, as follows:

TECHNIQUE : ROTN CW

ARC START : 0°

ARC STOP : 100°

DOSE SET : 100 units

TIME SET : 1 minute

READY TO START shall now be displayed by the VDU.

(2) Change to ROTATION C-CW.

Step through the settings using the ENTER key. When the ARC STOP : 100° is reached, the message ARC START/STOP INCOMPATIBLE shall appear; also it shall not be possible to continue and obtain READY TO START.

(3) Back space with the ERASE key and change the ARC STOP setting to 260°.

Step through the settings, pressing the ENTER key until confirmation that a compatible Arc Stop setting has now been made is indicated by the display of READY TO START.

(4) Back space with the ERASE key again and change ARC START to ±4° from the true gantry angle.

Step through the settings using the ENTER key and confirm that it is not possible to obtain READY TO START when there is a difference of more than 3° between the actual and required gantry angles.

8.4.3 Degrees/Unit Dose Range : Maximum Setting

Check that the maximum degrees/unit dose setting is 1.99, as follows:

(1) Set up a treatment with a gantry arc of 100° and a dose of 50 units. The message OUT OF RANGE - DEG/DOSE = 02.00 shall result and it shall not be possible to proceed any further through the setting-up sequence.

(2) Change the dose to 51 units. It shall now be possible to complete the setting-up sequence and obtain READY TO START.

8.4.4 Degrees/Unit Dose Range : Minimum Setting

Check that the minimum degrees/unit dose setting is 0.1, as follows:

(1) Set up a treatment with a gantry arc of 20° and a dose of 201 units. The message OUT OF RANGE - DEG/DOSE = 00.09 shall result and it shall not be possible to proceed any further through the setting-up sequence.

(2) Change the dose to 200 units; it shall now be possible to complete the setting-up sequence and obtain READY TO START.

8.4.5 Arc Fault Termination : Absence of Motor Drive

(1) Simulate a failure of the motor drive system by removing Motor Control board PWB62-A (MCC Level 2).

(2) Set a gantry arc of 100° and a dose of 100 units.

(3) Complete the settings and start the treatment. Termination shall occur at 4 dose units and the message GANTRY ANGLE FAULT - DIFFERENCE = 8 (or less) shall be displayed, together with TERMINATED ABNORMALLY.

8.4.6 Arc Fault Termination : Degrees/Unit Dose Linearity

Set Arc Start, Arc Stop and Dose values shown in the tables below and record the arc travelled clockwise according to the gantry scale. Repeat with the gantry rotating in a counter-clockwise direction.

With 200 dose units set:

Arc	40°	80°	120°	160°
Arc covered CW				
Arc covered CCW				
Allowable arc	40° ±2	80° ±2	120° ±3	160° ±3

With 100 dose units set:

Arc	100°	125°	150°	199°
Arc covered CW				
Arc covered CCW				
Allowable arc	100° ±3	125° ±3	150° ±3	199° ±3

If the arc travelled by the gantry is outside the tolerance allowed for the set arc, in any instance, termination shall occur and the message GANTRY ANGLE FAULT - DIFFERENCE = 8 (or less) shall be displayed, together with TERMINATED ABNORMALLY.

8.4.7 Arc Fault Termination : Degrees/Unit Dose Linearity under Wedge Field Conditions

(1) Set up an arc-therapy treatment in a clockwise direction, with wedged field, as follows:

TECHNIQUE : ROTN CW
ARC START : 0°
ARC STOP : 30°
WEDGE DOSE : 30 Units
TOTAL DOSE : 60 Units
TIME SET : 1 minute

The message SETTINGS COMPLETE shall be displayed when the wedge is in position. On pressing the ENTER key, READY TO START shall appear.

(2) Start the treatment:

- The message RADIATION - WEDGE IN shall be displayed and radiation shall commence.

- Directly the wedge dose of 30 units has been delivered over the set arc, the message RADIATION - DELAY shall appear on the VDU and irradiation shall cease (p.r.f. inhibited) for about 5 seconds while the wedge is withdrawn from the field.

- Note precisely the gantry scale angle reading for the position reached. This shall be 30 ±2 degrees.

(3) Gantry rotation and irradiation shall automatically resume directly the wedge has been withdrawn from the field; the remaining 30 units of the total dose shall be delivered over the return arc to 0°, concluding with normal termination.

(4) If the arc travelled by the gantry is outside the stated limits, termination shall occur and the message GANTRY ANGLE FAULT - DIFFERENCE = 8 (or less) shall be displayed, together with TERMINATED ABNORMALLY.

(5) Repeat the procedure given in (1) to (3) above, but for gantry movement in the opposite direction, i.e.

TECHNIQUE	:	ROTN CCW
ARC START	:	0°
ARC STOP	:	330°

The gantry angle reached shall be 330° ±2 degrees, failing which termination shall occur as described in (4) above.

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Chapter 4: MONITOR AND CONTROL CABINET

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1. GENERAL INFORMATION

- Circuit diagram : 4513 329 6000 Gp. 130, Shts. 1, 2 - Interconnections

The Monitor and Control Cabinet (MCC) is mounted on the right-hand side of the Gantry Support Frame Assembly and contains circuits for monitoring the performance of the equipment, also power output stages for the beam centring control systems, control circuits for the Gantry drive motors and the calibration of the movements position readout data. It also contains the a.c. mains distribution area, the -300 volts and low-voltage power supplies, and a cable termination panel.

The cabinet comprises a rear frame, hinged at its right-hand side to the rear side up-right of the Gantry Support Frame Assembly, and secured by two long bolts in guide tubes on its right-hand side, into screw-threaded sockets on the front side-upright of the Gantry Support Frame Assembly. Occupying the frame are four vertical chassis' (Fig. 2). Surrounding the frame and screwed to it is a box cover with a full length lockable door, giving access to the components at all Levels. Removal of the above-mentioned two bolts from within the cabinet allows the unit to be swung out and back on its hinges, thus giving access to side components of the Support Frame Assembly and to the rear of the Levels in the MCC.

2. LEVEL 1 : VACUUM, H.T. AND MAGNETRON FILAMENT MONITORING, CENTRING SUPPLIES AND DATA READOUT

2.1 BRIEF DETAILS

- Circuit diagram : 4513 329 6100, Gp. 130

Level 1 contains circuits for vacuum monitoring, H.T. voltage and magnetron current monitoring, beam centring coil supplies and data readout calibration. The front panel is in two parts. The left-hand side has a removable cover beneath which is a panel with eight coaxial sockets and two jumper leads; these are used to route signals from monitoring points in the machine to two test points on the engineer's panel of the TCC where the signals can be viewed on an oscilloscope (see Chapter 5 : Treatment Control System). The right-hand side of the front panel carries the VACUUM meter; this plugs in to a jack socket on the panel and can be transferred to a jack socket at the TCC for vacuum monitoring from there.

The vacuum meter is attached to the front panel of Level 1 by vertical key-hole slots in its back plate, which engage with two studs on the panel. Its connecting lead is wound round its mounting pillars and between a post to prevent it unwinding; the short free-end of the lead is then plugged into the nearby VACUUM monitor socket. Thus, the Vacuum Meter may readily be detached from Level 1 for use at the TCC when required.

The functions of the six monitor sockets used (two are spare) are evident from their titles which are given below, together with their circuit references.

R.F. MON (SK-C)	THY.I (SK-E)
THY.DRIVE (SK-D)	MAG.V (SK-F)
TP.1 (SK-K)	TP.2 (SK-L)

For normal everyday operation, the two 'jumper' leads are usually left connecting MAG.V to TP.1 and THY.I to TP.2, for ready monitoring from the TCC.

Protection for the MAG.V monitor point (should R1 and R2 go open circuit) is afforded by a spark gap and zener diodes ZD1 and 2 on TB1 (circuit diagram 4513 326 3000 130-1).

Printed wiring boards in Level 1 (Fig. 3) have the following functions:

PWB61-A : H.T. and magnetron filament monitoring;

PWB61-B,C,D,E : 1T, 1R and 2T, 2R centring power amplifiers;

PWB61-F : Data readout calibration and ±10 volts supplies;

PWB61-H, J : Data readout calibration;

PWB61-L : Vacuum monitoring.

NOTE

The wiring connections for another board, PWB61-K, are shown on circuit diagram 4513 329 6100 are for the optional 'Asymmetric Diaphragms' system.

2.2 VACUUM MONITORING : PWB61-L

This circuit monitors the operating current of the ion-pump power supply as a measure of the state of the vacuum in the waveguide. Included are fault-trip circuits that operate at vacuum limits of 2×10^{-4} and 2×10^{-5} torr. For full details, see Chapter 8 : Vacuum System.

2.3 H.T. AND MAGNETRON FILAMENT MONITORING : PWB61-A

Circuits on this board monitor the H.T. current through the modulator and the output voltage from the magnetron filament supply. The H.T. current monitor is a progressive trip circuit with three stages that operate at three levels of H.T. current. The first two stages control relays in the magnetron filament power supply to prevent the magnetron being overdriven (see Chapter 7 : Microwave System); the third stage is an H.T. overload trip which causes machine shut down when operated (see Chapter 6 : Modulator System). The magnetron filament voltage monitor is an under-voltage trip that operates when the magnetron filament supply output is too low (see Chapter 7 : Microwave System).

2.4 BEAM CENTRING SUPPLIES : PWBs 61-B,C,D,E

The functions of these four driver and power amplifier boards for the beam centring coil currents are:

PWB61-B : 1T centring

PWB61-C : 1R centring

PWB61-D : 2T centring

PWB61-E : 2R centring

The four circuits of these four boards are identical and are described in Chapter 9 : Beam Control System.

2.5 DATA READOUT CALIBRATION

The data readout calibration circuits at Level 1 provide stabilised ±10 volts d.c. supplies for position readout potentiometers in the Gantry and P.S.S.; they also buffer and calibrate the signals from these potentiometers. The calibrated signals are routed to the TCC for data readout (and Assisted Set-up where applicable).

- Circuit diagrams:

PWB61-F : 4513 326 6164, Gp.130

PWB61-H : 4513 326 6174, Gp.130

PWB61-J : 4513 326 6176, Gp.130

2.5.1 Readout Calibration Board : PWB61-F

PWB61-F contains two voltage regulators which produce +10 volts and -10 volts readout supplies from the ±15 volts rails. It is essential that the voltages of the ±10 volts readout supplies closely track each other with respect to machine zero volts. This is achieved by making the -10 volts supply basically a unity gain inverter amplifier using the +10 volts supply for its input.

A buffer and calibration circuit for the gantry angle readout signal is additionally included on the board. The buffer and calibration circuit consists of two operational amplifiers, the first of which buffers the input signal and the second which provides offset and gain adjustment facilities. The Stop Angle and Degrees/Unit Dose analogue functions are no longer used; they are now incorporated in the TCC. Buffer amplifier IC1 and potentiometers RV1, RV2 and RV3 shown in the circuit diagram are therefore not used.

The use of a ±10 volts (originally ±4.5 volts) range of position-signal for the 0 - 360° movements (i.e. gantry, radiation head/diaphragms, turntable and table angles) relates to the ±180° scale calibration used for earlier machines. The integrated circuits of the present TCC require only positive polarity signals, and the necessary 0 - 360° conversion is now made in the TCC on PWBs 76-AB and 76-D.

2.5.2 Readout Calibration Boards : PWBs 61-H and J

PWBs 61-H and J each contains four buffer and calibration circuits. PWB61-H handles the readout signals for the inner and outer diaphragms, the diaphragm system (radiation head) and the P.S.S. turntable; PWB61-J handles the treatment table height, table angle, table-top lateral and table longitudinal readout signals. All the circuits are functionally identical but some component values are different. Each circuit consists of a buffer amplifier followed by a calibration amplifier which has offset and gain adjustment facilities.

2.6 SETTING UP THE DATA READOUT

2.6.1 General Requirements

- Remember always to switch off the machine L.T. before removing and refitting PWBs.

- All the calibration boards must be in place while calibration work is in progress, otherwise the performance of the A-D Converter boards (PWB76-D and 76-AB) will be adversely affected.

- Take great care not to short-circuit adjacent tracks of the PWB when using the DVM probes.

- Allow an initial warm-up time of about five minutes before taking meter readings.

- A 4½ decade DVM is recommended. A 3½ decade DVM is acceptable but it will involve some reiteration of measurement and take a longer time to obtain the required accuracy of readout at the VDU.

2.6.2 Data Readout Supplies

The design of the ±10 volts regulator circuit ensures that the voltage of the -10 volts data readout supply tracks that of the +10 volts data readout supply accurately with time and temperature. Because the TCC senses only the +10 volts supply voltage, not the -10 volts supply voltage, check first that the +10 volts supply is correct at its origin on PWB61-F of the MCC, then transfer measurement to the TCC to ensure accuracy, within a positive tolerance, at the point of reference. The calibration of the A-D Converter and Multiplexer PWBs at the TCC is also included here for convenient reference.

(1) Connect the DVM between pins U and A on PWB76-AB (ADC Multi-plexer) in the TCC. Adjust RV6 on PWB61-F to give 10.000 volts ±2 mV.

(2) On PWB76-AB, temporarily link IC4-pin 3 to buffered analogue 0V (or link pins A and B if LINK fitted). Connect the DVM between pins V and A, and adjust RV1 on PWB76-AB to give 5.000 volts ±2 mV.

(3) At the TCT select Option 5 : DIAGNOSTIC; then at the TCC, on PWB76-D, adjust RV3 (Offset) and RV4 (Gain) for the following display readings:

0V REF	0 ±1
10V REF	4000 ±1
DIAPHR ROTN	2000 ±1

(4) Remove the temporary short on PWB76-AB (or remove link from pins B and C if fitted).

2.7 SETTING UP THE MECHANICAL MIDPOINT

Before carrying out readout calibration, first make any necessary mechanical adjustments to the coupling arrangement of the appropriate readout potentiomter so that, at the midpoint of mechanical travel of the movement, the output voltage is zero ±100 mV.

2.7.1 Setting-up the Gantry Angle Midpoint

In the case of the Gantry Angle potentiometer, proceed as follows:

(1) Rotate the Gantry to exactly 0° (check with a spirit level).

(2) Connect a DVM between the wiper of the Gantry Angle potentiometer RV1 and the end of a wire taken back to analogue 0V at PWB76-AB, pin A, in the TCC.

(3) Release the shaft coupling of the Gantry Angle potentiomter RV1, then rotate the shaft manually until the DVM reads zero ±100 mV. Carefully tighten the coupling and check that the DVM still indicates zero ±100 mV.

(4) Using Option 5 display, adjust RV5 on PWB76-D (ADC board) to give GANTRY CAL = 2000 ±1. Check that the Option 4 display gives GANTRY ANGLE as 0°.

2.8 METHOD OF CALIBRATING THE MOVEMENTS

The method uses formulae which do away with the need for repetitive sequential adjustments of the Gain and Offset potentiometers on the Readout Calibration boards. Thus, after setting the mechanical midpoint, proceed as follows:

(1) Connect a DVM to the appropriate readout monitor point on either the ADC board PWB76-D or the ADC Multiplexer PWB76-AB (see Table, Fig. 1 for details).

NOTE

Use the DVM on extension leads so that it can be read while setting the controls on the Readout Calibration boards in the MCC.

(2) Set the movement to position A (units) and note the readout voltage on the DVM; call this 'a' (mV). Set the movement to position B (units) and note the readout voltage on the DVM; call this 'b' (mV).

(3) Calculate $G = \frac{b}{b-a} \times$ (calibrated voltage change)

$$= \frac{b}{b-a} \times (B - A)s \text{ mV},$$

where s = calibration sensitivity in mV/unit.

NOTE

The units used for A, B and s must be compatible (e.g. if A, B are in cm, s is in mV/cm).

(4) While at position B, adjust the appropriate Gain control on the relevant Readout Calibration board to give this calculated value of 'G' (mV) on the DVM.

(5) While still at position B, calculate:

$$D = sB + \frac{s}{2} \times (\text{smallest unit}) \text{ mV}.$$

Adjust the appropriate Offset control to give this calculated value of 'D' (mV) on the DVM.

(6) Use the Option 4 display to confirm that the readout of 'B' is now correct. Move to position 'A' again and confirm that the readout of 'A' is correct. If not, repeat the above procedure.

2.8.1 Calibration Formulae

The calibration formulae are evaluated as follows:

(a) Rotational Movements

$s = 25$ mV/degree.

$$G = \frac{25b}{b - a} (B - A) \text{ mV};$$

$D = 25B + 12$ mV.

(b) Diaphragms Linear Movements

$s = 25$ mV/mm $= 250$ mV/cm.

With 'A' and 'B' in cm,

$$G = \frac{250b}{b - a} (B - A) \text{ mV};$$

$D = 250B + 12$ mV.

(c) Table Linear Movements

$s = 5$ mV/mm $= 50$ mV/cm.

With 'A' and 'B' in cm,

$$G = \frac{50b}{b - a} (B - A) \text{ mV};$$

$D = 50B + 2$ mV.

2.8.2 Calibration of Rotational Movements : Gantry and P.S.S.

Use the following procedure to calibrate the rotational movements listed in Table, Fig. 1, which also gives the relevant PWB, potentiometer controls and the high/low positions of the movement.

(1) Fit the appropriate PWB to an extender card and connect a DVM to the monitor point (see Table, Fig. 1).

(2) Set the movement to its mechanical zero position and check that the DVM reads ±0.1 volt. If not, adjust the mechanical position of the readout potentiometer to obtain this reading.

(3) Set the movement to 'A' in Table, Fig. 1. Note the DVM reading and call it 'a' (mV).

(4) Set the movement to 'B' in Table, Fig 1. Note the DVM reading and call it 'b' (mV).

(5) Calculate 'G' and 'D' from calibration formulae (a) in clause 2.8.1. Then:

- Adjust the appropriate Gain control to give the reading 'G' on the DVM;

- Adjust the appropriate Offset control to give the reading 'D' on the DVM.

(6) Check that VDU Option 4 displays the angle 'B'.

(7) Using the mecahnical scale, check that the readout on the VDU is correct for other angles of movement.

2.8.3 Calibration of Diaphragm Field-size

Use the following procedure to calibrate the diaphragm field-size, referring to Table, Fig. 1 as required. Note that it assumes that the optical field-defining system has been set up correctly beforehand (see Chap. 2):

(1) Fit PWB61-H to an extender card and connect a DVM to the monitor point (see Table, Fig. 1).

(2) Set the diaphragm field-size to the nominal midpoint position, (i.e. 'X' and 'Y' field-size to 20.0 cm) and check that the DVM reads zero ±0.1 volts. If not, adjust the mechanical position of the appropriate readout potentiomter to obtain this reading.

(3) Set the diaphragm field-size to 'A' by means of the optical field-defining system. Note the DVM reading and call it 'a' (mV).

(4) Set the field-size to 'B'. Note the DVM reading and call it 'b' (mV).

(5) Calculate 'G' and 'D' from calibration formulae (b) in clause 2.8.1.

- Adjust the appropriate Gain control to give the reading 'G' on the DVM;

- Adjust the appropriate Offset control to give the reading 'D' on the DVM.

(6) Check that VDU Option 4 displays the set field-size.

(7) Alter the position of the diaphragms and check that the VDU display is correct for other 'X' and 'Y' field-sizes. Make any fine adjustment required for the smaller field-sizes using the Offset control; if this is done, a slight adjustment of the Gain control may be required at maximum field-size.

2.8.4 Calibration of Diaphragm System Rotation (Head Angle)

Proceed as follows, referring to the Table, Fig. 1 as required:

(1) Remove the radiation head cover. Rotate the Gantry to 90°. Make sure that the Auto-Wedge Filter unit is uppermost, then place a spirit level on the framework of the diaphragm system and adjust the head angle until the face is level. The diaphragm system is now at 0°.

(2) Fit PWB61-H to an extender card and connect a DVM to the monitor point (see Table, Fig. 1). Check that the DVM reads zero ±0.1 volt. If not, adjust the mechanical position of the readout potentiometer to obtain this reading.

(3) Rotate the Gantry to 0°.

(4) Switch-on the optical field and dim the room lights so that the projected image of the crosswires can be seen on a surface (floor or table). Trace the image of the crosswires on to a sheet of paper secured to the surface and draw a radial line on the paper at 30° to one crosswire.

(5) Rotate the diaphragm system through 30° to the 30°-line on the paper and call this angle 'A'. Note the DVM reading and call it 'a' (mV).

(6) Rotate the diaphragm system a further 150° to the 180°-position, measured by rotating the crosswires image relative to the tracing on the paper; call this angle 'B'. Note the DVM reading and call it 'b' (mV).

(7) Calculate 'G' and 'D' from calibration formulae (a) in clause 2.8.1. Then:

- adjust the appropriate Gain control to give the reading 'G' on the DVM;

- adjust the appropriate Offset control to give the reading 'D' on the DVM.

(8) Check that the diaphragm system rotation (head angle) displayed on the VDU is 180°. Rotate the diaphragm system to the other cardinal points and check that the VDU display of angle is correct.

2.8.5 Calibration of Table Linear Movements (Lateral, Longitudinal and Height)

NOTES

1. To obtain the correct height of the table for readout calibration, set the Gantry to 0° and use the mechanical front pointer to establish the isocentre (100 cm from the target). This gives the setting 'A' in Table, Fig. 1. Next, lower the table until its top surface is 45 cm below the isocentre by measurement. This is the setting 'B' = 145 cm in Table, Fig. 1.

2. More precise measurements of the table lateral or longitudinal movements may be obtained by securing a sheet of graph paper to the table surface and positioning the table by reference to the image of the crosswires on the paper (head angle at 0°).

Proceed as follows, referring to Table, Fig. 1 and the Notes as required:

(1) Fit PWB61-J to an extender card and connect a DVM to the monitor point.

(2) Set the movement to its mid-position (e.g. Table Longitudinal has range 0 - 70 cm, so set it to 35 cm). Check that the DVM reads zero +0.1 volt. If not, adjust the mechanical position of the readout potentiometer to obtain this reading.

(3) Set the table movement to position 'A'. Note the DVM reading and call it 'a' (mV).

(4) Set the table movement to position 'B'. Note the DVM reading and call it 'b' (mV).

(5) Calculate 'G' and 'D' from calibration formula (c) in clause 2.8.1. Then:

- adjust the appropriate Gain control to give the reading 'G' on the DVM;

- adjust the appropriate Offset control to give the reading 'D' on the DVM.

(6) Check that the VDU displays the table setting 'B' correctly.

(7) Using the P.S.S. mechanical scales, check that the VDU readout is correct for other positions of the table movement.

2.8.6 Alternative Method of Calibration

Direct electrical measurement is preferred; the alternative method which uses the VDU readout instead of a DVM is likely to involve some reiteration of adjustment before correct results are obtained.

For the alternative procedure, proceed as follows, referring to Table, Fig. 1 for the necessary details:

(1) Set the movement parameter concerned to position 'A'.

(2) Note the movement readout, call it 'a'.

(3) Set the movement to position 'B'.

(4) Note the movement readout, call it 'b'.

(5) Calculate 'G' from the formula:

$$G = (B - A)\frac{b}{b - a}$$

(6) Adjust Gain potentiometer for a readout 'G'.

(7) Adjust Offset potentiometer for a readout 'B' (movement still in position 'B').

(8) Set the movement to position 'A' and check that the readout corresponds.

(9) If necessary, repeat the procedure until the correct readouts are obtained in both 'A' and 'B' positions.

3. LEVEL 2 : GANTRY MOVEMENTS CONTROL

- Circuit diagram : 4513 329 6200, Gp. 130

Contained on this Level (Fig. 4) are the motor control boards and relays for the Gantry movements, and two ±24 volts unregulated power supplies. One of these supplies is used locally for driving the small h.p. motors and is the source of the a.c. synchronisation for the thyristor power control of the large h.p. Gantry drive motor. The other ±24 volts power supply is for the Patient Support System. Mains power is obtained via the movements circuit breaker CB10 and the Stop Motors contactor CON60-D on Level 4.

Circuit boards on Level 2 and the motorised movements that they control are:

PWBs 62-A and B : Gantry rotation

PWB62-C : Radiation head diaphragms rotation

PWB62-D : Outer diaphragms position

Movement Parameter	Monitor point w.r. to PWB76-AB, pin A	Calibration Board			Position		Calibration Formulae
		PWB	Gain control	Offset control	A	B	
Gantry Angle	PWB76-D, pin 5b	61-F	RV5	RV4	0°	180° CW	Sec. 2.8.1 (a)
Diaphragm (Head) Angle	PWB76-AB, Pin Z	61-H	RV6	RV2	30°	180° CW	
PSS Table Angle	PWB76-AB, pin 10	61-J	RV7	RV3	0°	180°	
PSS Turntable Angle	PWB76-AB, pin K	61-H	RV5	RV1	0°	100°	
Diaphragm 'X'	PWB76-D, pin 13b	61-H	RV7	RV3	3.0 cm	30.0 cm	Sec. 2.8.1 (b)
Diaphragm 'Y'	PWB76-D, pin Nb	61-H	RV8	RV4	3.0 cm	30.0 cm	
PSS Table Lateral	PWB76-D, pin Kb	61-J	RV6	RV2	80.0 cm (80.0)	120.0 cm (20.0)	Sec. 2.8.1 (c)
PSS Table Longitudinal	PWB76-D, pin 10b	61-J	RV5	RV1	5.0 cm	65.0 cm	
PSS Table Height	PWB76-D, pin 11b	61-J	RV8	RV4	100.0 cm (0.0)	145.0 cm (45.0)	
+ 10 V Reference	PWB76-AB, pin U	61-F	RV6		10.000 V ± 2mV		

Figure 1: Data for Movements Readout Calibration

PWB62-E : Inner diaphragms position

Relays on Level 2 and their control functions are:

RL62-A : Mains supply to gantry motor thyristor power control board

RL62-B : Gantry motor logic control and RL62-A control

RL62-C : ±24 volts to diaphragms (radiation head) motor

RL62-D : ±24 volts to diaphragms X-field motor

RL62-E : ±24 volts to diaphragms Y-field motor

RL62-J : Primary control of ±24 volts supply

RL62-K : System ready interlock

Additional positions are provided for relays RL62-F and H which are only fitted when the 'Asymmetric Diaphragms' option is included.

The motor control circuits are fully described in Chapter 10 : Movements Control System.

4. LEVEL 3 : -300 VOLTS AND L.T. POWER SUPPLIES

- Circuit diagram : 4513 329 6300, Gp. 130

Level 3 (Fig. 5) receives its mains power via L.T. circuit breaker CB4 at Level 4 (see text 5).

Power supplies generated at Level 3 are as follows:

+24 and -24 volts unstabilised d.c. supplies for the TCC;

+9 volts (nominal) unstabilised d.c. (with OV return) for the TCC 5 volts regulated d.c. supply;

+15 and -15 volts stabilised d.c. supplies for linear integrated circuits throughout the machine;

-300 volts unstabilised d.c. for the ionisation chamber in the radiation head.

The -300 volts supply is routed to the ionisation chamber via the gantry pre-amplifier unit. It provides a negative polarisation supply to all three sections of the ionisation chamber, and is thence routed back through the gantry pre-amplifier unit to the TCC. There it is applied to two potential dividers which provide stepped down voltages for the -300 volts Supplies Fault Detector (PWBs 76-H and K) and for monitoring the -300 volts supply voltage at the Engineer's Panel (PWB76-MM).

5. LEVEL 4 : MAINS DISTRIBUTION AND TERMINATION PANEL

- Circuit diagram : included in 4513 329 6000, Gp. 130 Sht. 1, 2

Level 4 contains a.c. mains distribution equipment for the entire machine, together with a termination panel for all plug and socket and terminal strip interconnections between the MCC and other areas. The Level has a front panel with apertures through which a row of circuit breakers, a timer and two hour-meters project. The panel can be removed by undoing six screws, to provide access to the circuits and interconnections behind (Fig. 7).

5.1 MAINS DISTRIBUTION

The 3-phase and neutral a.c. mains supply from the customer's isolator is fed into the machine on terminal strip TS1. Ten circuit breakers are used to distribute the supply to all parts of the equipment (see Fig. 8). Three of these, CB1, 2 and 3 are connected directly to the supply and so are always live. They provide power for the following:

- CB1 : Single-phase 240 volts a.c. to the 24 volts a.c. interlocks supply transformer T1 and to the TCC;

- CB2 : Single-phase 240 volts a.c. to the vacuum ion pump power supply in the Gantry;

- CB3 : 3-phase supply to the Water Cooler.

The remaining seven circuit breakers are connected to the supply via contacts of the Supplies On contactor CON60-A and therefore are not live until the equipment is switched on (see Chapter 3 : Interlocks). These circuit breakers provide power as follows:

- CB4 : Single-phase 240 volts a.c. to the L.T. power supplies at Level 3 and to the Treatment Room Display (VDU).

- CB5 : 3-phase supply to the focus power supplies in the Gantry. The output from the circuit breaker is switched by the Focus Start relay RL60-B and the Focus On contactor CON60-B (see Chapter 3 : Interlocks).

- CB6 : 3-phase supply to the H.T. transformer in the Modulator. The output from the circuit breaker is switched by the H.T. Start relay RL60-C and the H.T. ON contactor CON60-C. The H.T. Hours meter is also driven from one phase of this supply. HSE switch kit machines have an extra contactor 60-E in series with RL60-C and CON60-C (see Chapter 3 under "ROOM INTERLOCKS"). Contactor 60-E is linked out on non-HSE machines.

- CB7 : Single-phase 240 volts a.c. to the gun filament power supply in the Gantry. The output from the circuit breaker is switched by the Gun On relay RL60-A.

- CB8 : Single-phase 240 volts a.c. to the magnetron filament power supply in the Gantry. This supply is also used for the cooling fans in the Modulator and Gantry, and for thyratron supplies, clipper trigger etc. circuits (see Chapter 6 : Modulator System). The L.T. Hours meter is driven from this supply.

- CB9 : Single-phase 240 volts a.c. to the field optics transformers in the Gantry. The output from the circuit breaker is switched by relays to provide optical field-defining and SSD indication. The relays are controlled by push-buttons mounted on the Movements Controller.

- CB10 : Single-phase 240 volts a.c. to the Movements Control circuits at Level 2 (see Chapter 10 : Movement Control System) and the P.S.S. The output from the circuit breaker is subject to overriding control by the Stop Motors contactor CON60-D.

6. MAINTENANCE OF CONTACTORS

WARNING

ENSURE THAT MAINS SUPPLIES ARE SWITCHED OFF BEFORE SERVICING THE CONTACTORS.

The contacts of the FOCUS, H.T. and STOP MOTORS contactors should be checked at 3-monthly intervals for signs of wear, and should be cleaned or replaced as necessary. It is not possible to service the contacts of CON60-E or the SUPPLIES ON contactor, CON60-A.

Check the servicability of the FOCUS, H.T. and STOP MOTORS contactors CON60-B, C and D as follows:

(5) Undo the middle screw on each side of the contactor. Remove the small clips and the plastic combs that cover the contacts.

(6) The fixed contacts are removed by undoing their retaining screws.

(7) To remove a moving contact, grip the contact with snipe-nosed pliers, turn it through 90 degrees and withdraw it from its guides. Take care that the small spring and end plate do not fall out at the same time.

(8) The contacts are refitted by reversing the above procedures. Make sure that the moving contacts are able to move freely after they have been refitted.

* * * * *

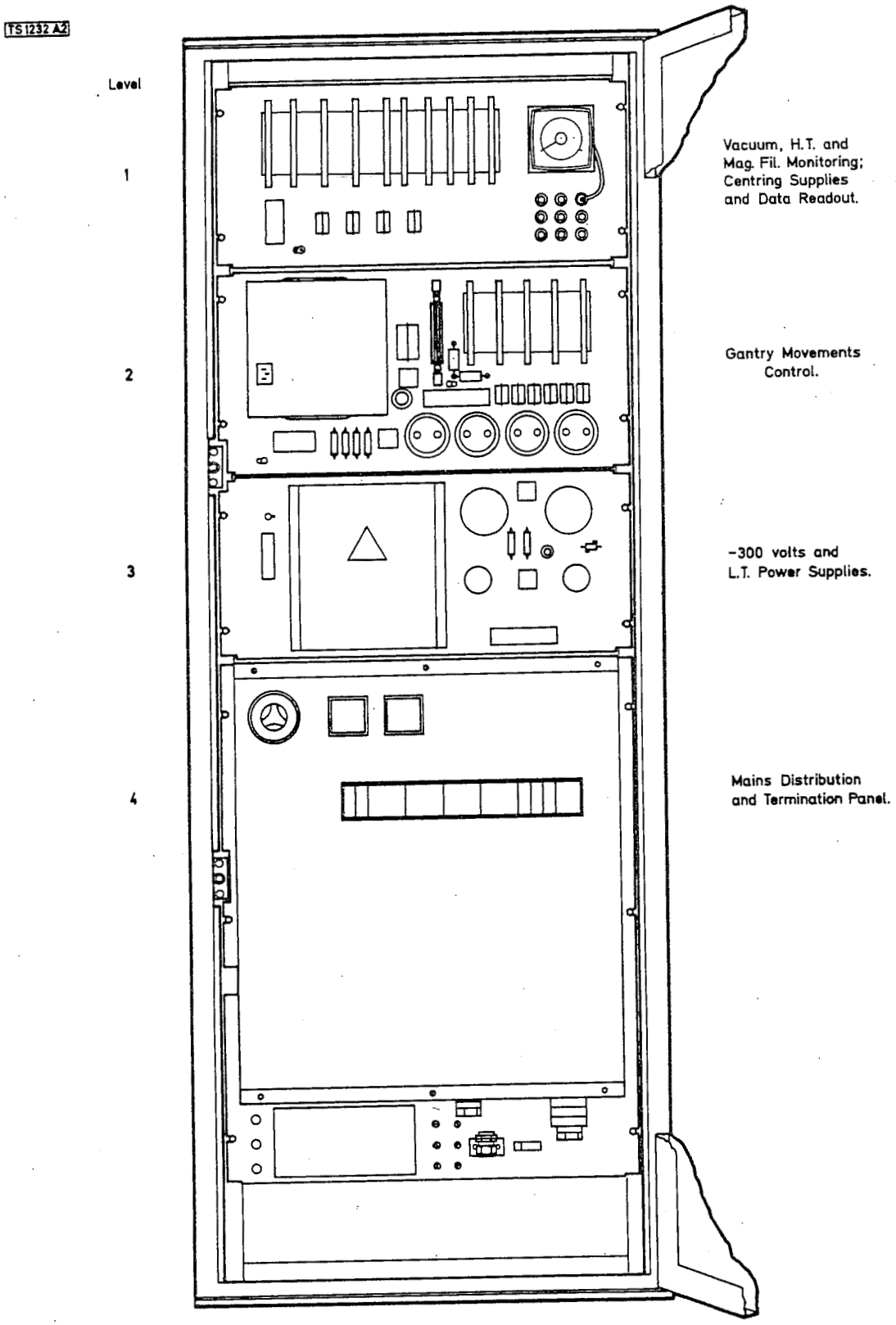
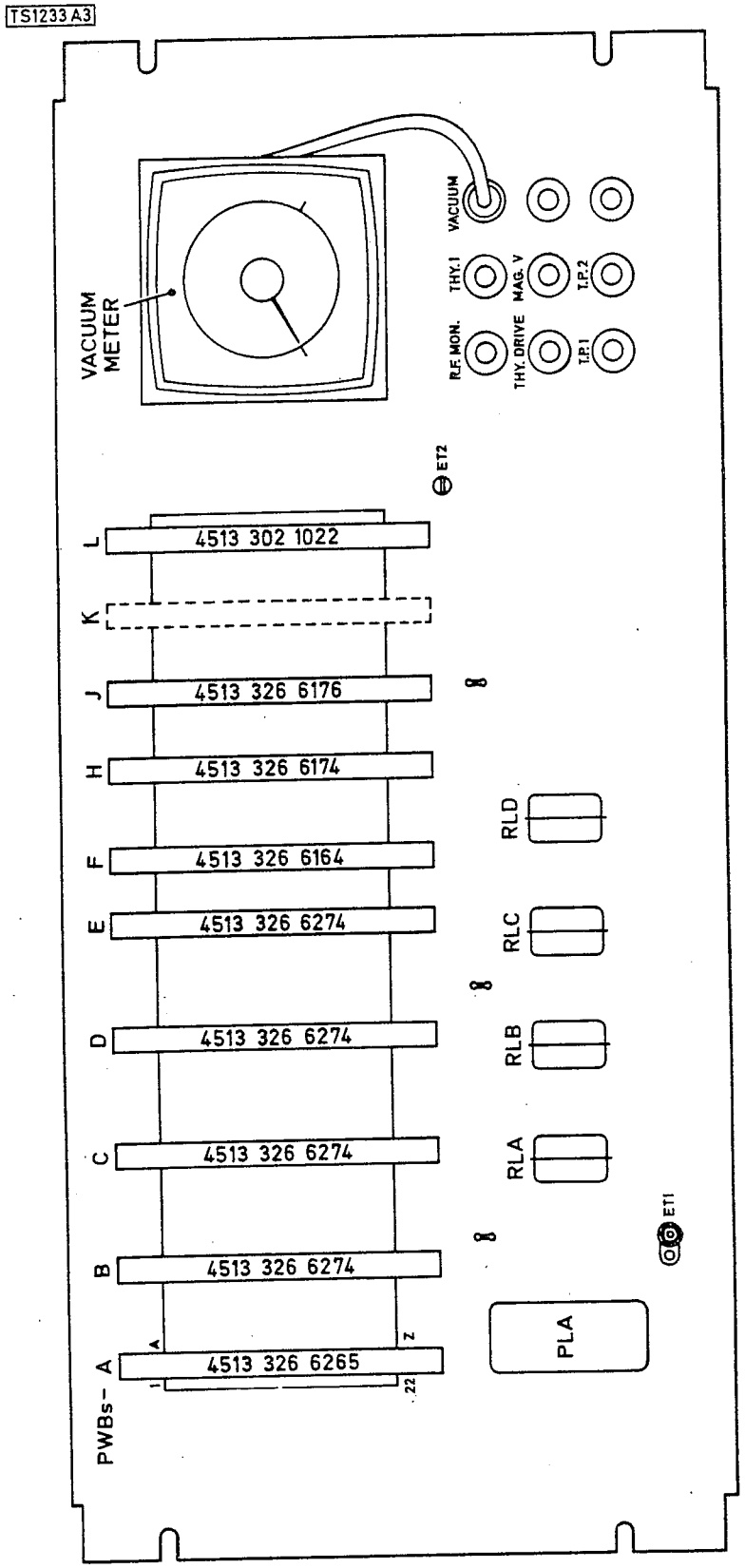
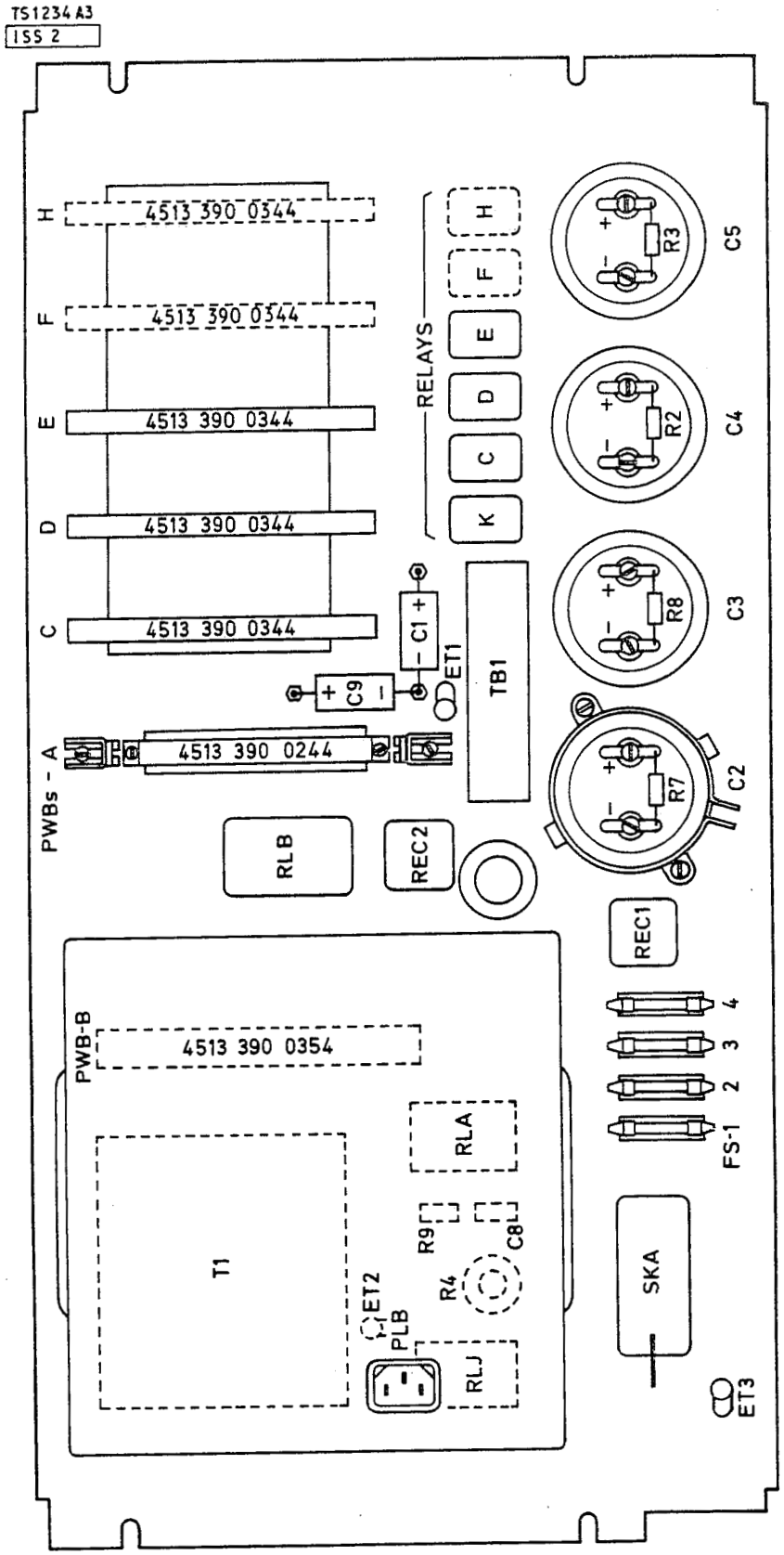


Figure 2: Monitor and Control Cabinet, front interior view



Note: Level 1 components are denoted in circuit diagrams by prefix '61', e.g. PWB61-A etc.
When assymetric diaphragms are fitted,
PWB H becomes 4513 326 6178
PWB K becomes 4513 326 6179

Figure 3: MCC Level 1 - Component Layout



Note: PWBs F & H, Relays F & H fitted for 'Asymmetric Diaphragms' option only.
Level 2 components are denoted in circuit diagrams by prefix '62', e.g. PWB62-A, RL62-K etc.

Figure 4: MCC Level 2 - Component Layout

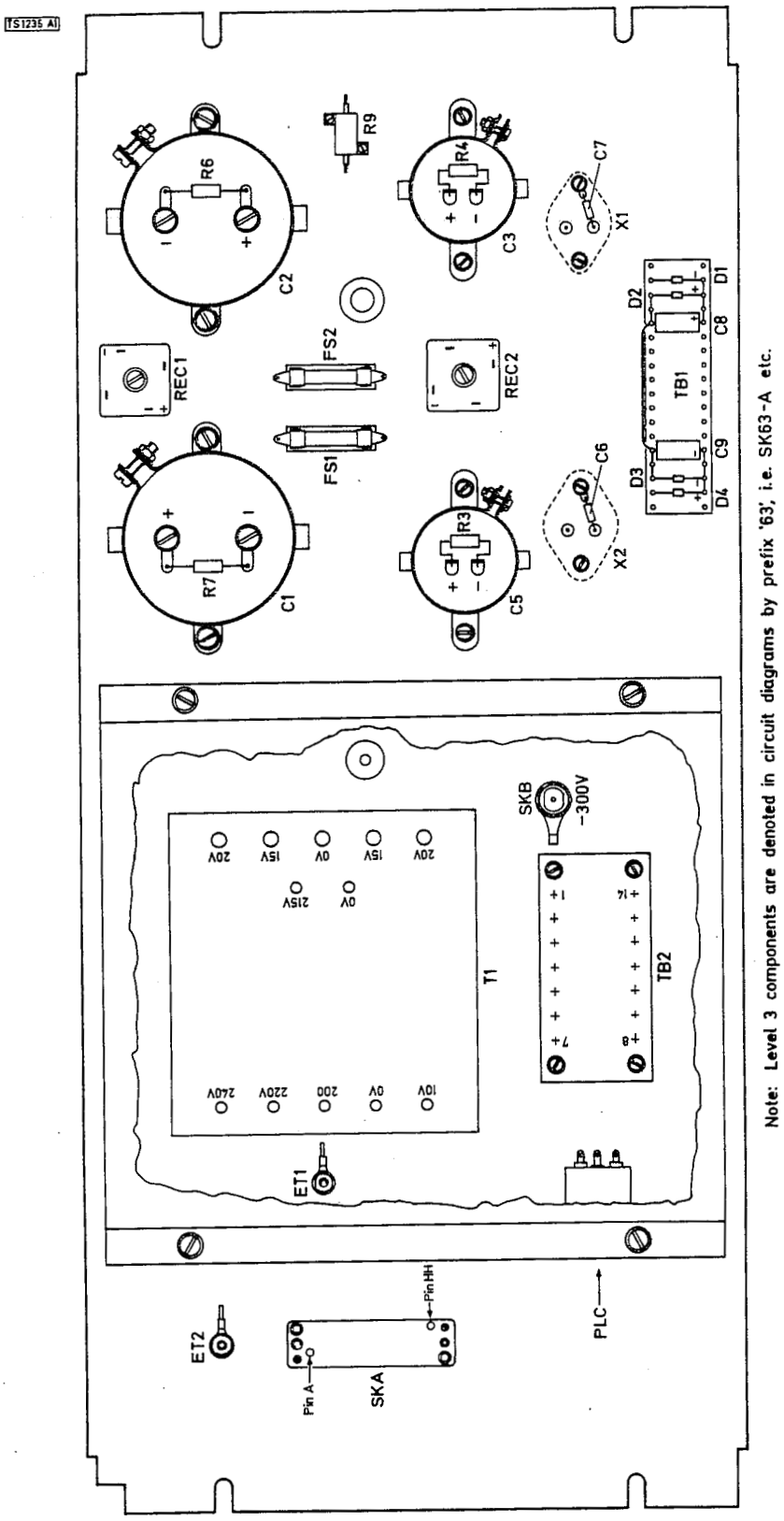
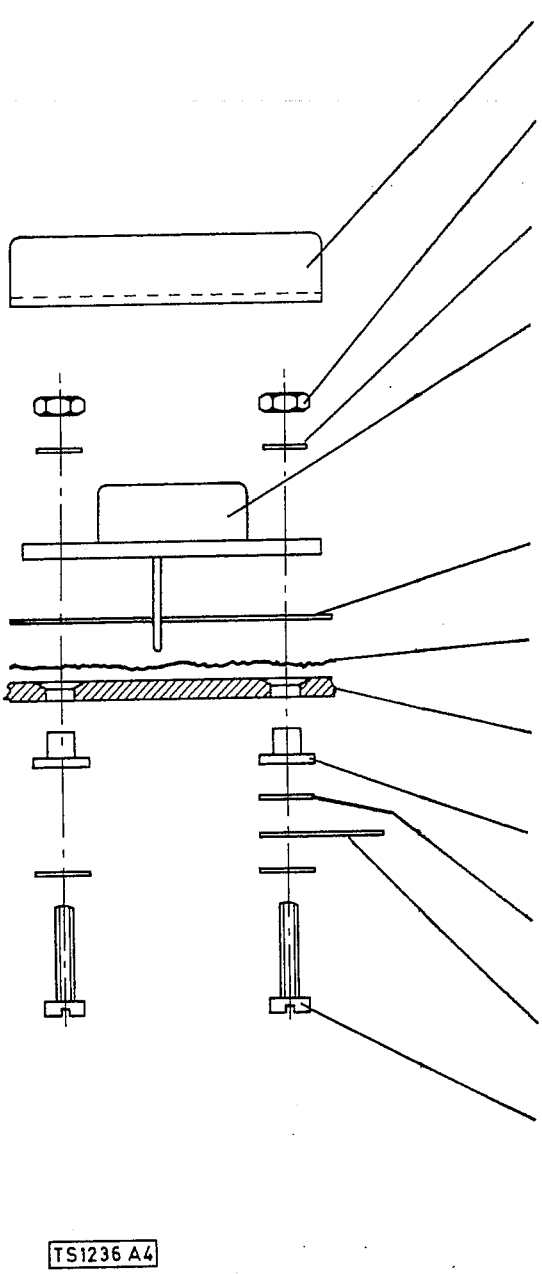
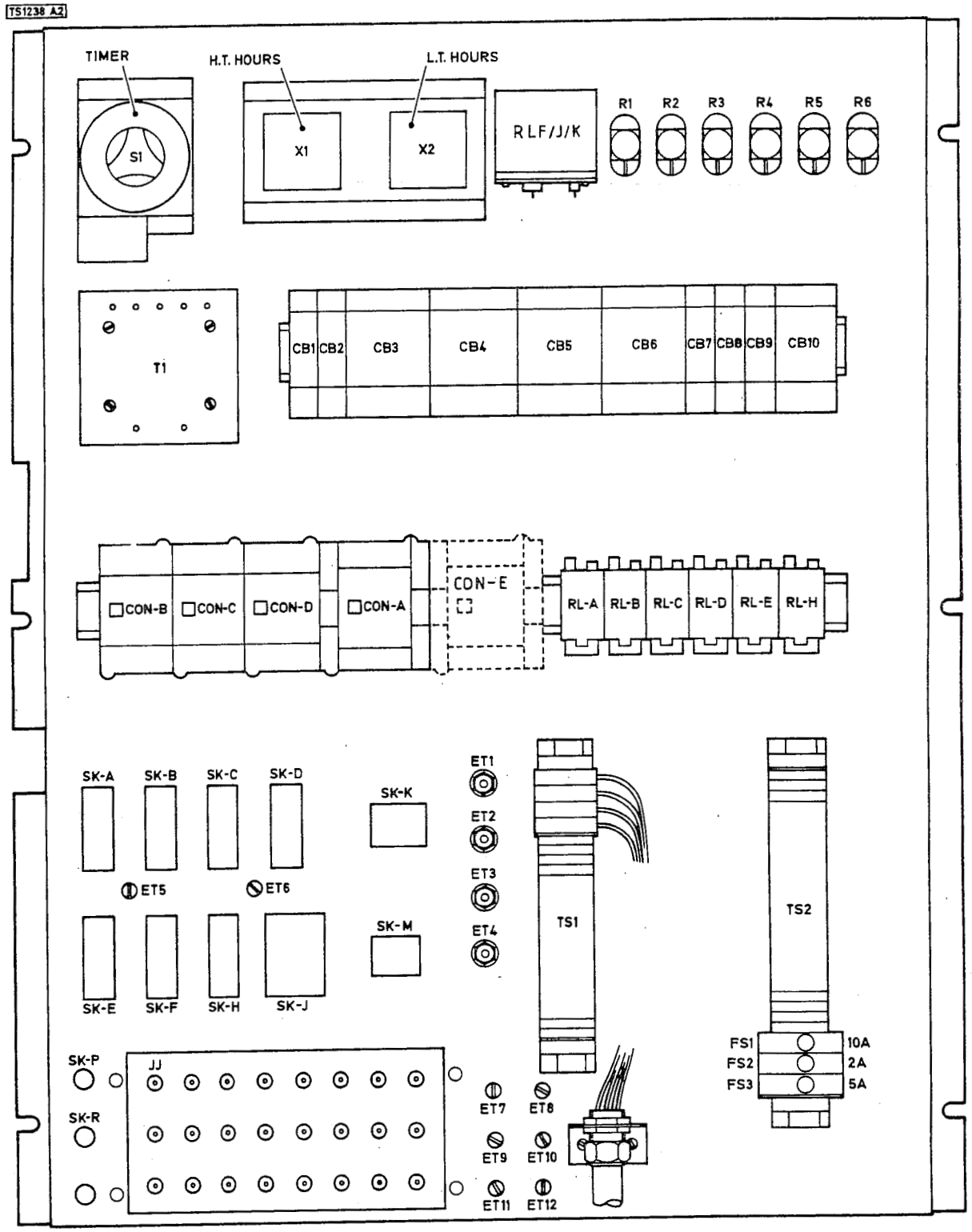


Figure 5: MCC Level 3 - Component Layout


Isolating cover
Nut, full, St. Stl., M3 (x2)
Washer crinkle, St. Stl., M3 (x2)
X1, LM 340 K15
OR
X2, LM 320 K15
* Washer, insulating, TO-3, mica
Compound, heat-sink, white
Chassis
Bush, insulating, TO-3 (x2)
Washer, plain, St. Stl., M3 (x3)
Tag, solder, M3
Screw, Pan, Slotted, M3 X 10 St. Stl. (x2)
TS1236 A4

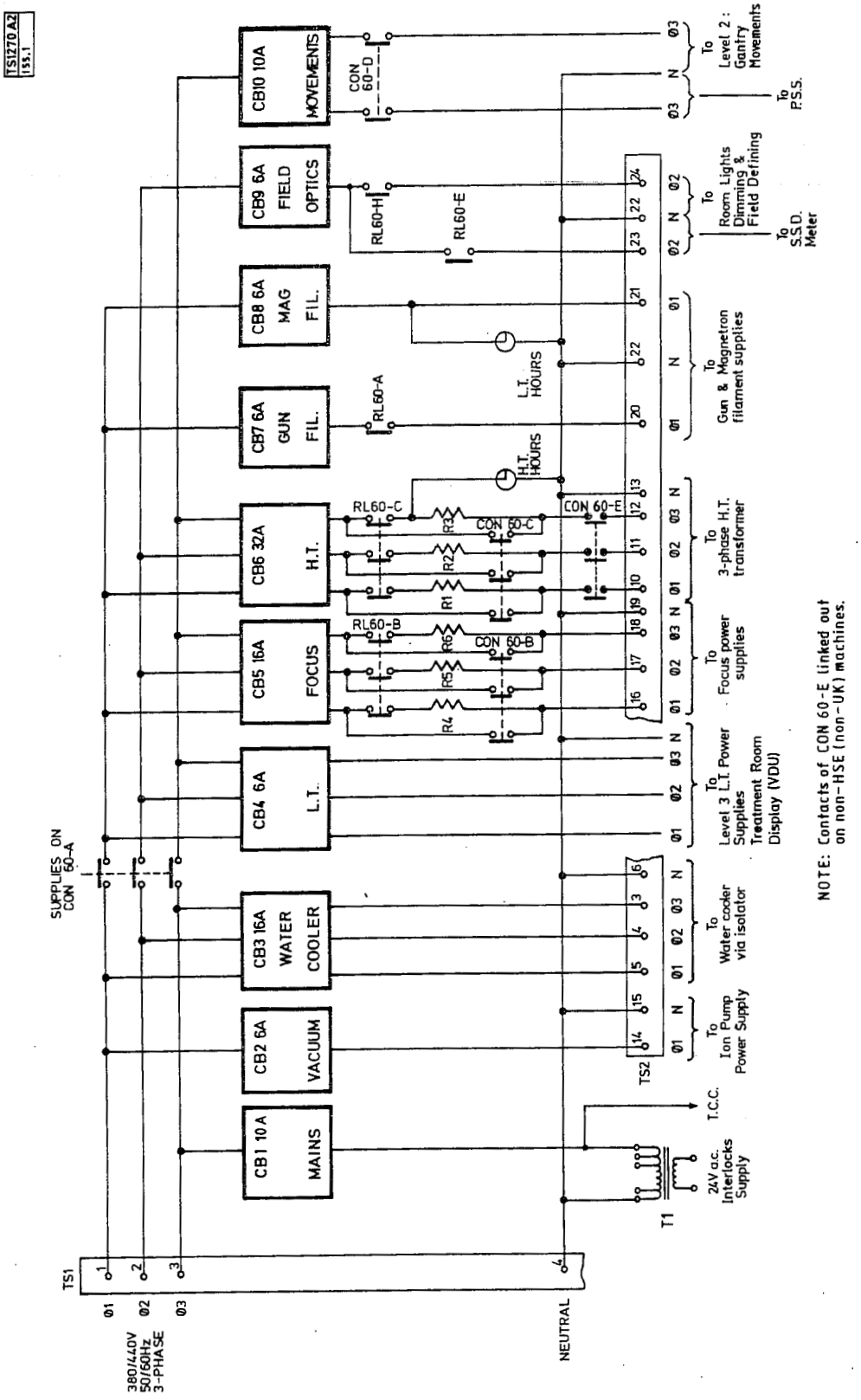
* Note: Do not fit mica washer when fitting X1

Figure 6: Mounting details for X1 and X2 (Level 3)



Note: Level 4 components are denoted in circuit diagrams by prefix '60', e.g. RL60-A, CON60-E etc.

Figure 7: MCC Level 4 - Component Layout, front panel removed



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1. GENERAL INFORMATION

The Modulator provides the high power pulses which drive the magnetron in the Linac, the pulses being generated by a pulse-forming network (P.F.N.), which is resonantly charged from a d.c. supply and discharged by a hydrogen thyratron switch. The voltage to which the P.F.N. is charged is accurately controlled by a clipper circuit and the pulse repetition rate is set by a p.r.f. generator in the Treatment Control Cabinet (TCC). The high voltage power supply for the Modulator is accommodated in the Gantry Support Frame Assembly and consists of a 3-phase transformer, bridge rectifier and capacitor. Included in the Modulator are the following:

- Pulse-forming network,
- Thyratron and Supply,
- Thyratron Pulser.
- Clipper Trigger,
- Reverse Diode Overload Detector.

Circuit Diagrams:

- Modulator and Gantry Support Frame Assembly : 4513 329 2000, Gp. 130
- Gantry Circuit : 4513 326 3000, Gp. 130, Shts. 1 and 2

2. MODULATOR

2.1 H.T. POWER SUPPLY

The 380/440 volts 3-phase mains supply from H.T. circuit breaker CB6 is switched by relay RL60-C and contactor CON60-C in Level 4 in the MCC and is applied via surge limiting resistors R1, R2, R3 to the primary windings of a 3-phase transformer T1 located in the Gantry Support Frame Assembly. On UK machines

only, the 3-phase supply is additionally controlled by contactor 60E as described in Chapter 3 of this volume under "ROOM INTERLOCKS". The transformer output is rectified by the 3-phase bridge rectifier D1 to D6 and the resulting high-voltage d.c. is smoothed by capacitor C5. R11 is a bleeder resistor for discharging C5 when the supply is switched off. Current monitoring and H.T. overload protection is derived from the voltage developed across R2 which is connected between H.T. negative and the 'pulse earth' line.

2.2 CHARGING CIRCUIT

The Modulator employs resonant charging of the pulse-forming network X5. Between pulses, the hydrogen thyratron switch V1 is non-conducting and the H.T. supply charges the P.F.N. via charging transformer T2, R6/R7/R8 and charging diode D8. During the charging cycle, the P.F.N. may be considered as a lumped capacitance C_N, since only its capacitive elements have appreciable impedance at the charging frequency. Capacitance C_N forms a series resonant circuit with the primary inductance of T2, and the voltage across the network increases sinusoidally until it reaches approximately twice the H.T. supply voltage. Current reversal is prevented by diode D8 and the P.F.N. remains charged to the maximum voltage of the charging waveform.

Because of charging circuit losses, the final voltage V_N to which the P.F.N. would be charged without clipper control is approximately 1.85 times the H.T. supply voltage. With clipper control, V_N is slightly less and the P.F.N. remains charged at this level until the hydrogen thyratron switch is triggered, whereupon the network is discharged via the pulse transformer in the Gantry.

2.3 DISCHARGING CIRCUIT

When the hydrogen thyratron V1 is fired, the P.F.N. is discharged, the negative pulse appearing at terminal T_O is fed out from the Modulator via a high-power coaxial cable to the primary winding of a dual bifilar-wound pulse transformer in the Gantry. The primary winding of the pulse transformer, when loaded by the magnetron across the secondary, has an impedance approximately equal to the characteristic impedance Z_O of the P.F.N. The voltage V_N is therefore shared equally between Z_O and the primary impedance e.g. if V_N is 18 kV, 9 kV will be applied across the primary, and since the pulse transformer has a voltage step-up ratio of 1:5, it will deliver an output pulse of approximately 45 kV (actually 44 kV).

The d.c. heater supply for the magnetron is fed through the bifilar windings, with balancing capacitors C6, C2 and C4 between the ends of the windings and across the filament.

2.4 REVERSE VOLTAGE PROTECTION

The effect of sparking in the magnetron immediately following a charging pulse, is to short circuit the load and generate a reverse voltage across the P.F.N. which, if not removed, will adversely affect the next charging cycle and may damage components in the Modulator. Any negative voltage appearing on the charging line, therefore, is removed by diode D7. In series with D7 are resistors R6/R7/R8, and R17 which is connected across the Reverse Diode Overload Protection circuit. The value of R6/R7/R8 is chosen so that the time constant C_N x R6/R7/R8 exceeds the deionisation time of the thyratron.

The zener diode in parallel with R17 protects the overload circuit from high transient voltages across R17, and also provides protection against R17 becoming open-circuit.

The Reverse Diode Overload Protection circuit monitors the voltage developed across R17 by any reverse current through D7. The circuit comprises a diode-pump integrator and voltage comparator, driving a 1-second timer with opto-coupler isolation of its output connection to the Reverse Diode Overload Trip circuit on PWB76-BB. Normally, output pin 7 of the voltage comparator IC5 is held at +15 volts via R14; consequently the timer IC3 is quiescent and its output is negative. This voltage is applied to opto-coupler IC4 which therefore conducts and negates the +6.85 volts PRF INHIBIT voltage residing at pin 3 of PWB76-BB, connected at SK60-p of the modulator.

The pulses developed across R17 progressively charge capacitor C8 through D9 and R21, the discharge path being via a longer time constant through R20 and R19. When the negative potential across C8 reaches about -12 volts i.e. it exceeds the initial +11 volts, approximately, at the junction of R19, R20 due to the current through D20, with respect to +7.5 volts at pin 3 of IC5 due to R16 and R17, the output of comparator IC5 changes state to negative. This switches on the timer IC3 whose output therefore goes positive and switches off opto-coupler IC4 for 1 second. IC4 output then rises from zero to enable the positive PRF INHIBIT voltage at PWB76-BB of the TCC. After 1 second the timer automatically resets, thereby resetting the fault detector circuit and restoring the p.r.f. output.

A fast diode, type BYV96E, is used to facilitate the pumping action of D9. D20 is conveniently of the same type and limits the initial positive potential across C8, as explained above, to +0.7 volt.

NOTE

Attention is drawn in the explanatory note on the circuit diagram, 4513 329 2000, in the vicinity of IC2 and IC5, which are both type LM311. It is given because, in the case of IC2, instead of taking the output from a collector load connected at pin 7, as normal, it is taken from the emitter of the device, at pin 1. Thus the polarity of the output from IC2 with respect to that of its inputs, is reversed compared to that of IC5.

2.5 H.T. VOLTAGE REGULATION

To ensure stability of the magnetron current pulses, it is necessary to regulate the voltage to which the P.F.N. is charged. A sample of the charging voltage is applied to the Clipper Trigger circuit via a potential divider comprising R9 and ZD1 on the modulator chassis and R9, C3 in the Clipper Trigger circuit; zener diode ZD1 protects the circuit board in the event of R9 in the modulator going low resistance or R9 in the Clipper Trigger circuit going high-resistance or open circuit. The signal is applied to the non-inverting input pin 3 of Comparator IC2, which has a positive reference voltage from preset variable resistor RV1 applied to its inverting input pin 2, so that the output of IC2 is

normally zero. (See above Note). The supply voltage for the reference potentiometer is regulated by R1 and two high-stability 6.2 volts (nominal) zener diodes, the range of control voltage sufficient for RV1 being taken from across one of them, ZD1. Diodes D1, D4, D5 and D6 protect IC2 from interference voltage spikes at its inputs. Whenever the magnitude of the voltage monitored at pin 3 of IC2 exceeds that at pin 2, the output of IC2 changes from zero to +15 volts. Consequently TR1 is switched on and the negative-going pulse at its collector results in a positive-going pulse from the 2 : 1 step-down transformer, T1. Diode D2 prevents the flow of reverse current and provides critical damping of T1 primary circuit.

The positive-going pulse appearing across the secondary of T1 is of 3.5 volts peak amplitude (typical) and is fed out at pins 22 and 23 of the Clipper Trigger circuit to the gate of the Clipper Thyristor CSR1 in the Heat Sink Assembly via a coaxial line. Diode D3 acoss the secondary of T1 provides reverse current protection for thyristor CSR1.

The clipper circuit consists of avalanche thyristor CSR1, R3/R4/R12/C3/C6 and the secondary of the charging transformer T2. The thyristor is protected from spikes by the damping circuit C4, R5. When CSR1 is triggered, current flows from the secondary of T2 into C3/C6, causing an effective short-circuit of the transformer and inhibiting charging of the P.F.N. The charge in C3/C6 is dissipated in R3/R4/R12. Components R1, C1 across the primary of charging transformer T2 provide critical damping when the clipper is inoperative e.g. at switch-on and switch-off: when the clipper circuit operates, damping is provided by the clipper action.

2.6 THYRATRON SUPPLIES

The secondary voltage of mains transformer T2 in the Modulator is full-wave rectified by bridge diodes D10 - D13, from which positive and negative 140 volts d.c. supplies are obtained with respect to pulse earth. After smoothing by C9, the +140 volts supply is used by the Thyratron Pulser (see 2.7). It is additionally filtered by C10, R23, C12 and applied via R16 to the first grid of the thyratron switch V1 to keep it permanently ionised. The second grid of the thyratron is biased by the -140 volts supply, applied to it via the secondary winding of T3 in the Thyratron Pulser circuit and resistor R14. The cathode lead of the thyratron is inductively coupled to the THY I socket at Level 1 of the MCC by a transformer coil encircling the base of the thyratron.

2.7 THYRATRON PULSER

Pulses for triggering thyratron V1 are fed to the Thyratron Pulser from the P.R.F. Generator on PWB76-CC in the TCC (See Chapter 5 for details). The pulses are typically of +15 volts amplitude and 2 microseconds duration. They are synchronised with the periodicity of the a.c. mains supply at pulse repetition rates selected by the P.R.F. switch on the engineer's panel in the TCC. On 50 Hz mains, the rates that may be selected are 50, 150 and 300 pulses per second; on 60 Hz mains, the rates available are 60, 180 and 300 p.p.s.

The thyratron trigger pulses are fed to the gate of Thyristor CSR1 via R30 and the 2 : 1 step-down, non-inverting, transformer T5. Diode D16 provides reverse

voltage protection for CSR1. Components L1, C13 to C16 and CSR1, together with D15 and the 6 Henry charging choke L2, constitute a pulse-modulator. The p.f.n., L1, is supplied with 250 volts d.c., maximum, obtained from the +140 volts and -140 volts unregulated supplies. Thyristor CSR1 is the switch for a pulse generating circuit consisting of the 2 microsecond pulse-forming network (L1, C13 to C16) and a pulse-inverting, thyratron drive transformer T3, with step-up ratio of 1:3. The network capacitances C13 to C16 are resonantly charged from the 250 volts supply, through L2, to about 500 volts. Charging diode D15 prevents reversal of current flow, while R13 protects L2 from overload in the event of a short circuit in the pulse modulator. Components D14, R25; D17, R26 and D19, R30 provide protection from transient reverse voltages.

When CSR1 is triggered, it conducts and discharges the pulse-forming network to produce a negative pulse of the order of 250 volts amplitude across the primary of T3. In T3, the pulse is inverted and stepped up to deliver a positive-going pulse of approximately 500 volts and 2 microseconds duration for firing the thyratron. The bias supply for grid 2 is connected via R4, R15 which provide a low impedance source to assist deionisation. R27, R28 across the secondary of T3 provide impedance matching. Capacitors C19 and C18 form a capacitive potential divider of 10:1 step-down ratio to permit monitoring of firing pulses on an oscilloscope. The signal is coupled to the THY DRIVE monitor socket at the MCC by an isolation transformer T4 and R29.

3. H.T. OVERLOAD PROTECTION

- Circuit Diagrams : 4513 329 0010, Gp.130, Sht.2 - H.T. Mag. Fil. Monitoring System

  4513 329 6100, Gp.130 - MCC Level 1, Relay Driver PWB61-A

  4513 326 3900, Gp.130 - Magnetron Filament P.S.U.

The Modulator H.T. supply current passes through R2 which is in the return path from 'pulse-earth' to the negative end of the H.T. supply. The voltage developed across R2 is applied to the H.T. overload circuit on PWB61-A at Level 1 in the MCC. Relays RL61-A, RL61-B and RL61-C in the H.T. overload circuit are normally energised through the conduction of TR1, TR2 and TR3 but become de-energised in turn as the H.T. current increases and the voltage across R2 progressively overcomes the zener voltages of ZD1, ZD2 and ZD3. It is also monitored at the engineer's panel on the TCC, after calibration by RV2 on PWB76-LL of the TCC.

In the first stage of voltage increase, relay RL61-A is de-energised when the current in R2 is between 150 and 250 mA, causing relay RLB in the Magnetron Filament Power Supply to be de-energised and so reduce the magnetron filament voltage by changing the tap on the secondary of the filament supply transformer. In the second state of voltage increase, relay RL61-B is de-energised when the current in R2 is between 360 and 480 mA, causing relay RLA in the magnetron filament supply to be de-energised, cutting off the filament supply completely (see Chapter 7 : Microwave System). In the final stage of voltage increase, relay RL61-C is de-energised when the current in R2 is between

825 mA and 1 A, causing the H.T. START relay RL60-C to be de-energised, in turn tripping contactor CON60-C and switching off the 3-phase supply to the H.T. transformer. At the same time the H.T. OVERLOAD indicator is illuminated on the TCC engineer's panel and TR1 in series with the VAC 10^{-4} relay RL76-C on PWB76-AA of the TCC is switched off, thus breaking the treatment interlocks chain.

4. MAINTENANCE INFORMATION

WARNING

TAKE GREAT CARE WHEN CARRYING OUT ANY WORK ON THE MODULATOR SYSTEM AS DANGEROUS VOLTAGES MAY BE PRESENT. ALWAYS USE THE INSULATED EARTHING ROD TO DISCHARGE THE H.T. STORAGE CAPACITOR C5 AND THE PULSE-FORMING NETWORK CAPACITORS BEFORE TOUCHING ANY MODULATOR COMPONENTS.

BEWARE OF MAINS VOLTAGES THAT REMAIN AT TERMINALS TS-1 TO 13 ON LEVEL 4 OF THE MCC EVEN IF THE 3-PHASE MAINS ISOLATOR IS SWITCHED OFF.

4.1 INSULATED EARTHING ROD

This is clipped inside the door of the Modulator Cabinet. It is a rod of fibre-glass 1.35 m (54 in.) long, with a brass hook at one end. A suitable length of heavy-gauge insulated cable is connected securely to the hook and its free end bolted to pulse-earth on the Modulator chassis.

4.2 H.T. SPARK GAP

The correct setting for the spark gap is 30 ±0.5 mm.

4.3 SETTING-UP THE H.T. SUPPLY

Ensure that the H.T. transformer T1 in the Gantry Support Frame Assembly is set for the correct tapping points. For this, the mains input tapping points on T1 primary should be connected to the next lower voltage, relative to the mains supply voltage; see following Table. It may, however, be necessary to depart from the nominal settings to obtain adequate clipping action, see 'Setting-up the Clipper Trigger'.

Phase-to-phase supply voltage	H.T. transformer tapping points
380-399 V	380
400-419 V	400
420-440 V	420
440-459 V	440

Continue as follows:

(1) Remove the anode connection of hydrogen thyratron V1 in the Modulator.

(2) Connect an EHT meter (15 kV f.s.d. or greater) to the output of the H.T. supply, at terminal 'S' REACTOR INPUT TERMINAL of transformer T1.

(3) Switch-on H.T. at the engineer's panel of the TCC. The H.T. voltage should rise to about 12 kV in two distinct steps, a fraction of a second apart.

(4) Switch-off H.T. and replace the anode connection of V1.

4.4 CHARGING CIRCUIT CHECK

Proceed as follows:

(1) Connect a coaxial lead between socket TP1 at Level 1 of the MCC and the junction of R9/ZD1 on the Modulator chassis.

(2) At the engineer's panel of the TCC, connect the oscilloscope to TP1 and TRIGGER.

(3) Select a p.r.f. of 300 p.p.s. (PRF select to position 3), then switch on H.T.

(4) Observe that a waveform is displayed as shown in Fig. 2. This waveform is derived from the potential divider R9 (3.3 M-ohm) on the modulator chassis and R9 (1.8 k-ohm) in the clipper circuit and so represents the charging voltage waveform at the anode of the charging diode D8.

The theoretical waveform at the P.F.N. is also shown in Fig. 2, the peak voltage being maintained by D8.

(5) Switch off H.T. and remove the coaxial lead from RV1 and TP1.

4.5 DISCHARGING CIRCUIT CHECKS

Proceed as follows:

(1) At Level 1 of the MCC, connect jumper leads between sockets THY.I and TP1, and sockets MAG.V and TP2.

(2) At the engineer's panel of the TCC connect the oscilloscope to TP1 and TRIGGER.

(3) Select a p.r.f. of 300 p.p.s., then switch on the H.T.

(4) Observe the thyratron current pulse. It should be of the form shown in Fig. 3 and should have the following characteristics:

- Amplitude : 480 to 495 A;
- Pulse width : 4.6 microseconds (measured at 50% amplitude).

NOTES

1. The calibration factor of the current transformer is nominally 50 A/V; however, the actual figure should be determined for the individual machine.

2. The thyratron current pulse represents fairly accurately the current pulse through the magnetron except that it is about five times the amplitude because of the 1:5 step-up ratio of the pulse transformer. Also the leading edge of the magnetron pulse will be significantly sharper. Correction factors in respect of these differences will be determined during installation tests.

(5) Connect the oscilloscope to TP2 on the engineer's panel of the TCC.

(6) Observe the magnetron voltage pulse. This should be of the form shown in Fig. 3 and should have the following characteristics:

- Amplitude : 44 to 46 kV;
- Pulse width : 4.0 microseconds (measured at 90% amplitude).

NOTE

The magnetron voltage monitor has a voltage divider ratio of approximately 2000:1; however, the actual calibration factor should be determined for each individual machine.

The amplitude of the current pulse is adjusted by RV1 in front of the Modulator Circuit box-cover. This determines the level of H.T. voltage at which the clipper operates. The adjustment is very critical and if it is altered, the correct operation of the clipper circuit must be checked at all p.r.f. rates.

4.6 CLIPPER TRIGGER CIRCUIT

4.6.1 Circuit Check

Check that clipper action is taking place by observing the magnetron voltage pulse signal using a long time-base, i.e. displaying at least two voltage pulses. Observe that a small negative-going 'pip' occurs on the trace between

the voltage pulses (see Fig. 3) and that clockwise adjustment of clipper control RV1 moves the 'pip' leftwards towards the voltage pulse and increases its amplitude. Check that the 'pip' is present and its posiion variable at all three p.r.f. settings. Proceed as follows:

(1) Connect a length of coaxial cable between the TP1 socket at Level 1 of the MCC and the Gate terminal of clipper thyristor CSR1.

(2) At the engineer's panel of the TCC, connect the oscilloscope to TP1 and TRIGGER.

(3) Select a p.r.f. of 300 p.p.s., then switch on H.T.

(4) Observe that a positive trigger pulse is displayed of the form shown in Fig. 4(a). Check that the negative overswing does not exceed 0.75 V.

NOTE

The spike at the beginning of the trace is caused by a surge through the clipper transformer T1 when the P.F.N. commences to charge.

(5) Switch off H.T. and disconnect the coaxial lead from socket TP1 and gate of CSR1.

The effect of clipper control on the charging waveform can be demonstrated by observing the charging waveform sample at the junction of R9 and ZD1 on the modulator chassis and noting that clockwise adjustment of RV1 moves the trailing (clipped) edge of the waveform to the left thereby reducing the voltage level to which the P.F.N. is charged before clipper action takes place.

4.6.2 Setting up the Clipper Trigger

Compare the two diagrams of the charging waveform in Figure 5. Diagram (a) shows the correct clipper setting, with the peak of the p.f.n. recharge waveform below the clipping level, while diagram (b) shows the unstable condition where the peak of the p.f.n. recharge waveform is as high as the clipping level, indicating that the clipper trigger control RV1 or the mains voltage taps on the H.T. mains transformer are inadequately set. The peak of the p.f.n. recharge waveform must be set below the clipping level. The setting-up procedure is as follows.

(1) Set the PRF to 50/60 p.p.s. (PRF selector to position 1).

(2) Adjust the clipper control RV1 to obtain the correct value of magnetron current as described in text 4.5.

(3) Observe the charging waveform sample at the junction of R9 and ZD1 on the modulator chassis.

(4) Check that the peak of the p.f.n. recharging waveform is below the clipping point as in Fig. 5(a). If it is not, change to the next higher mains voltage tappings on the H.T. mains transformer to reduce the H.T. voltage.

(5) Check that the clipper action and p.f.n. recharging levels are now correct at all p.r.f's, and that the normal radiation dose rate is attained.

4.7 THYRATRON PULSER CHECKS

With H.T. switched off, and taking care to observe the normal safety precautions, check that the voltages at the following points on the Thyratron pulser circuit measured with respect to pin 13 (pulse earth), are within the limits stated:

Test Point	Minimum	Typical	Maximum
+140 V supply:			
Pin 14 w.r.t. pin 13	+ 75 V	+ 100V	-
100 Hz ripple	-	5 V pk-pk	10 V pk-pk
-140 V supply:			
Pin 12 w.r.t. pin 13	-100 V	-130 V	-150 V
100 Hz ripple	-	5 V pk-pk	10 V pk-pk

Continue as follows:

(1) At the engineer's panel of the TCC connect the oscilloscope to TP1 and TRIGGER.

(2) At the Level 1 of the MCC, connect a jumper lead between sockets THY. DRIVE and TP1 to route the thyratron drive monitoring signal to TP1 of the TCC.

(3) Select a p.r.f. of 300 p.p.s., then switch on H.T.

(4) Observe that a positive thyratron trigger pulse is displayed of the form shown in Fig. 4(c). The pulse height should typically be about +50 volts peak with respect to pulse earth (0 V). Mean level of the pulse is at - 140 volts and the pulse width, measured at -50 volts, should be 2 microseconds approximately (1 microsecond minimum). The negative overshoot to -500 volts would be matched by a +500 volts peak if it were not for the clamping action of the thyratron grid, limiting it to +50 volts. Pulse width of the negative overshoot, measured at -300 volts, should be about 20 microseconds.

(5) Switch off H.T. The jumper lead may be left in a preferred position (see Chap.4).

4.8 REVERSE DIODE OVERLOAD CIRCUIT CHECKS

Proceed as follows:

(1) Connect the earthing rod to the high-power pulse cable termination on the P.F.N. thereby short-circuiting the Modulator output.

(2) Set the p.r.f. selector to position 1 (50/60 p.p.s.) then switch on H.T.

(3) Monitor the thyratron current pulse and check that the Modulator pulses are inhibited for a period of about 1 second every 5 seconds (250 pulses at a p.r.f. of 50 p.p.s.), thus indicating that the reverse diode overload trip is operating. The R. DIODE OVERLOAD indicator on the TCC engineer's panel should light when the pulses are inhibited.

NOTE

The thyratron current pulse will be of twice the normal amplitude.

(4) Switch off H.T., then remove the earthing rod from the P.F.N.

(5) Check that normal Modulator operation now takes place at all p.r.f. settings.

4.9 H.T. CURRENT MONITOR CHECKS

The H.T. current monitor is checked by a simulation method as follows:

(1) Connect a variable d.c. power supply (e.g. to 0 to 15 V, 0 to 1 A) in series with a multimeter across the H.T. current monitor resistor R2 (12 ohms) located on the L.T. component Board Assembly in the H.T. Power Supply (Chap. 2, Fig. 1) above the h.t. transformer in the Gantry Support Frame Assembly: ensure that the supply positive is connected to the pulse-earth end of R2, e.g. by reference to C2 in parallel with the resistor. Set the meter range to 1 A d.c.

(2) Increase the output voltage of the supply from zero until relay RL61-A at Level 1 of the MCC is de-energised. Check that the current at which this occurs is 200 ±50 mA.

(3) Continue to increase the output voltage of the supply until relay RL61-B at Level 1 of the MCC is de-energised. Check that the current at which this occurs is 420 ±62 mA.

(4) Continue to increase the output voltage of the supply until relay RL61-D at Level 1 of the MCC is de-energised. Check that the current at which this occurs is 912 ±87 mA. Check also that the H.T. OVERLOAD

indicator on the TCC engineer's panel is illuminated.

(5) At each stage, check that the monitor on the engineer's panel of the TCC (set to MAG I) registers the same reading as the multimeter.

Overall calibration of the MAG I Monitor meter is set by RV2 on PWB76-LL in the TCC.

(6) Remove the variable d.c. power supply and the multimeter from across R2.

(7) Check that with both RL61-A and RL61-B energised, the magnetron filament voltage is between 8.0 V and 9.0 V; that with RL61-A de-energised and RL61-B energised the magnetron filament voltage is between 4.0 V and 6.0 V; and that with both RL61-A and RL61-B de-energised the magnetron filament voltage is zero.

* * * * *

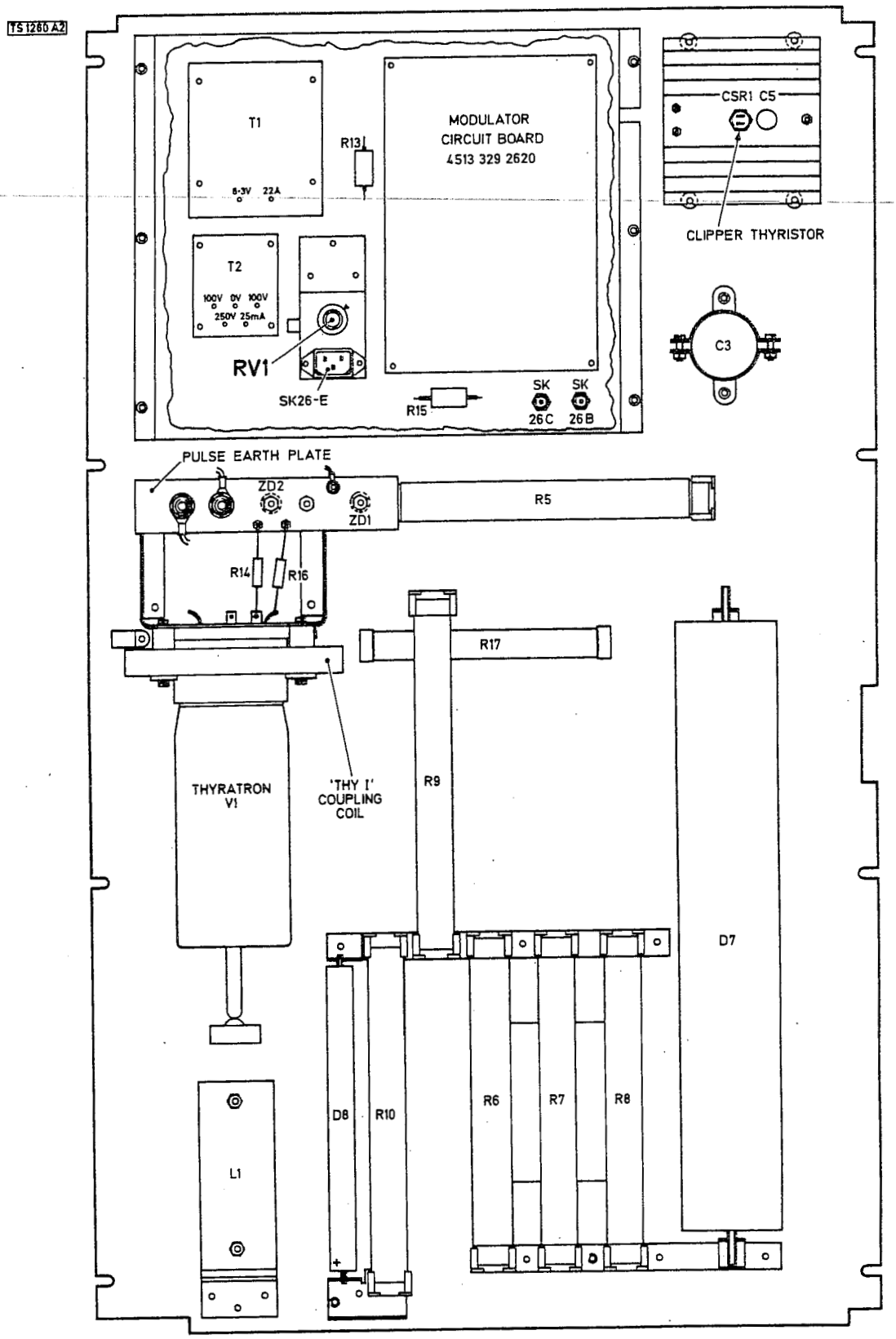


Figure 1: Modulator Chassis, component layout

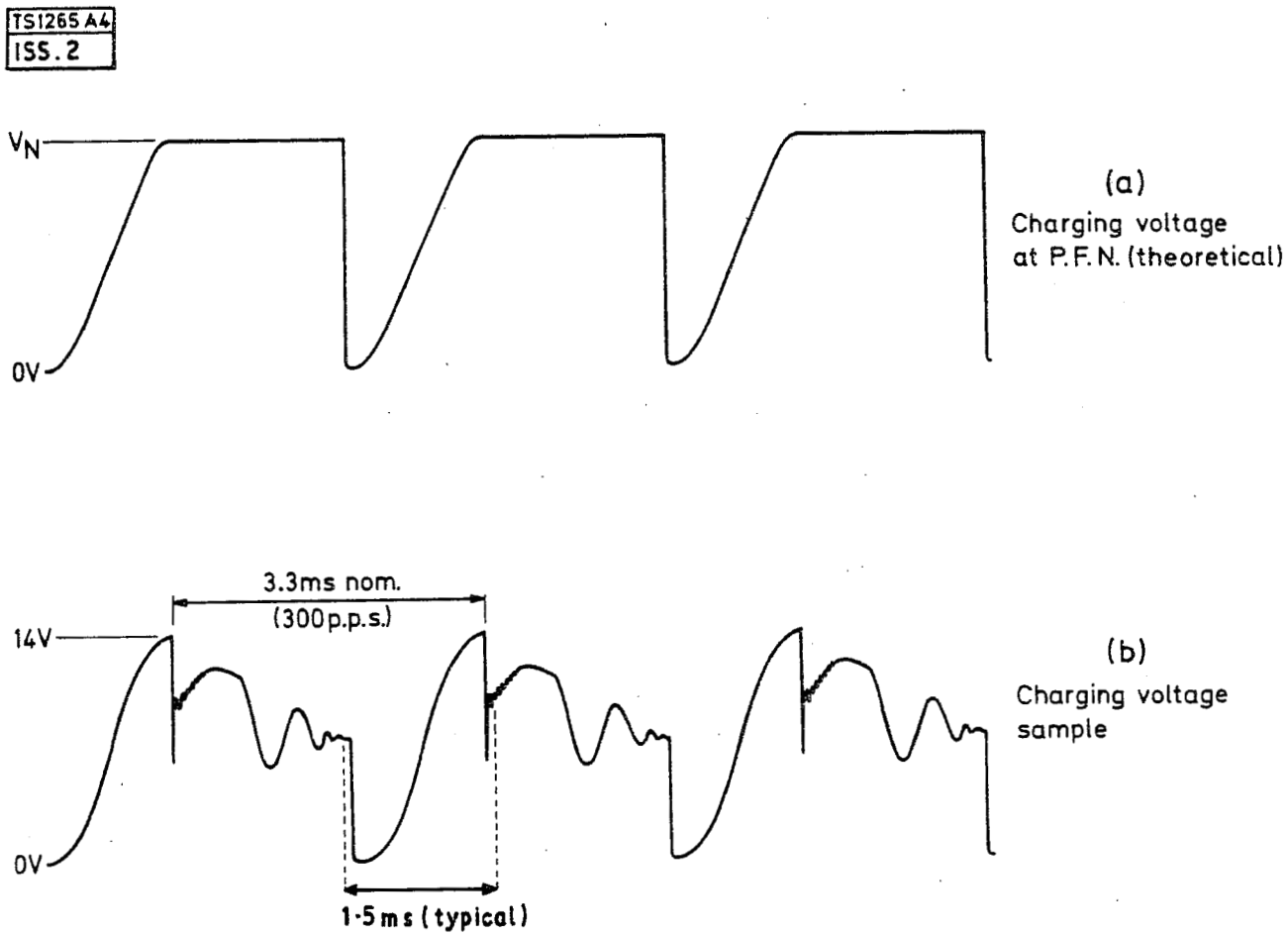


Figure 2: H.T.-P.F.N. Charging Circuit Waveforms

TS1266 A4

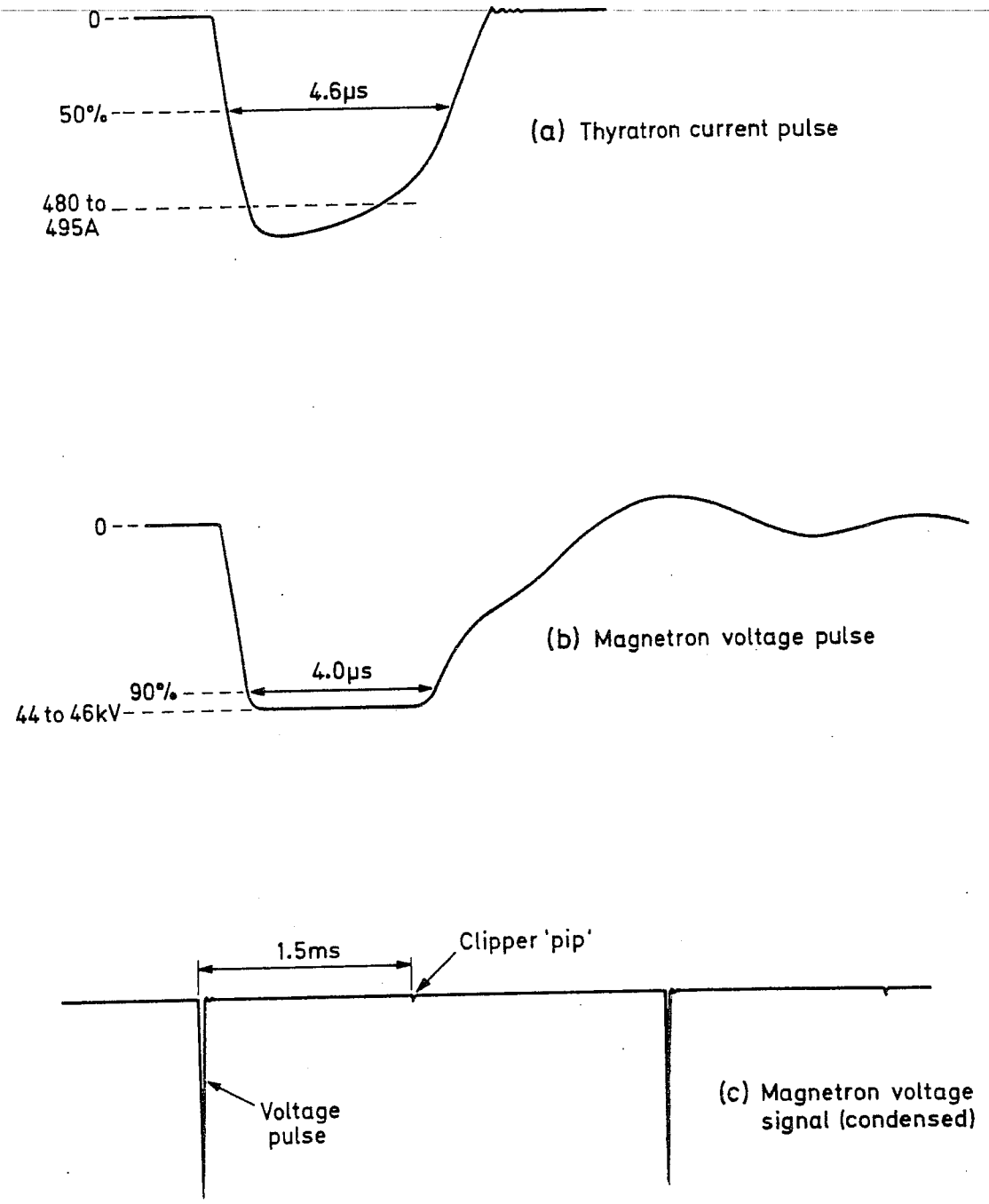


Figure 3: H.T.-P.F.N. Discharging Circuit Waveforms

TS1267A4

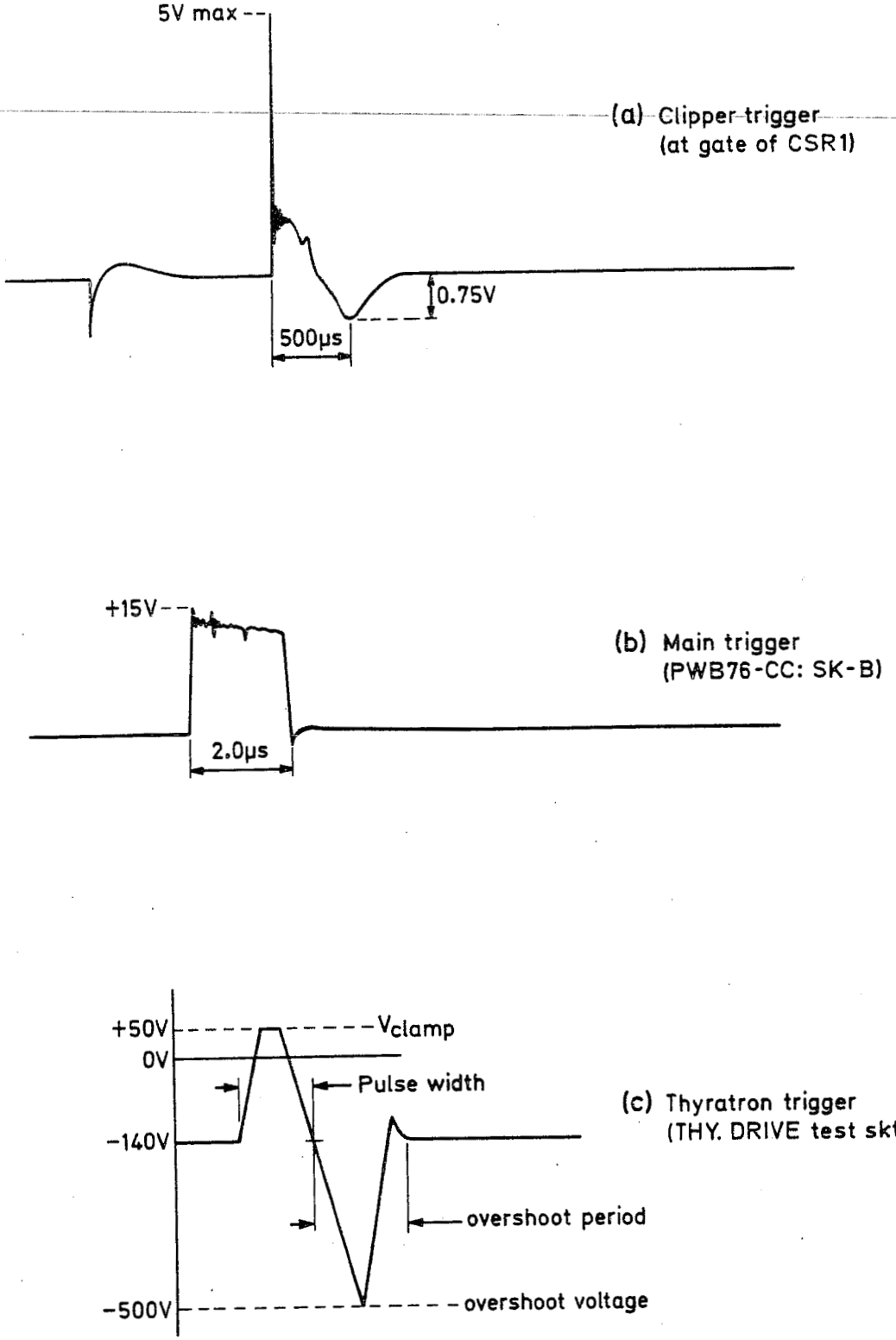
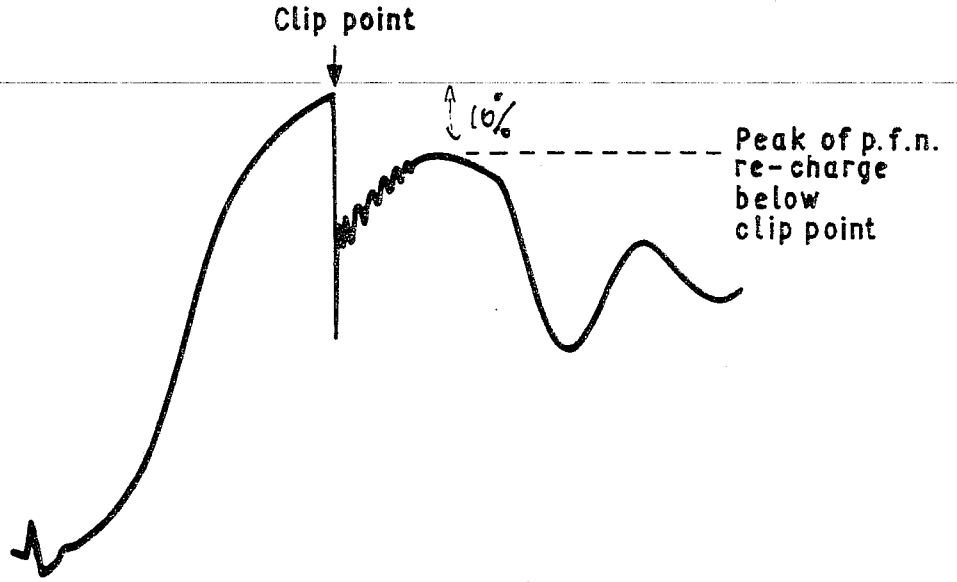
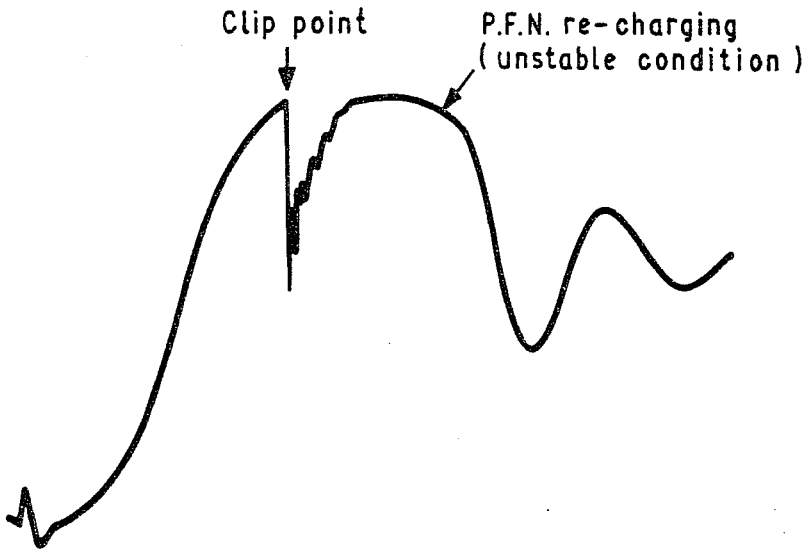


Figure 4: Trigger Waveforms

TS1268A4



(a) Correct clipper-trigger conditions



(b) Incorrect clipper-trigger conditions

Figure 5: Clipper Trigger Adjustment

Chapter 7: MICROWAVE SYSTEM

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1. GENERAL INFORMATION

The heart of the microwave system is the iris-loaded accelerator waveguide which accelerates electrons from their injection energy (45 keV approx.) to the selected final energy in the range 4 to 6 MeV. The electron energy is derived from interaction with the electromagnetic fields propagated as travelling waves in the accelerator. The electrons travel in near-synchronism with the waves and gain energy continuously from the axial electric-field component of the waves.

The microwave power is derived from a magnetron provided with automatic frequency control, and the power flows via an isolator and a rectangular waveguide system into the linear accelerator (see Fig. 1). In the accelerator waveguide the power is attentuated in two ways: by absorption on the internal

surface of the iris-loaded structure, and by transfer of power to the electron beam. At the output end of the accelerator the residual microwave power is extracted and absorbed without reflection, in a matched r.f. load. The accelerated electron beam, however, continues on through a drift tube and is then guided on to the target.

The rectangular waveguide system - including the magnetron transition section (circular to rectangular), high-power isolator and output r.f. load - is pressurised with compressed air to 2.1 bar (30 psi) to prevent r.f. breakdown in the waveguide, and is separated from the accelerator (which is maintained at high vacuum) by two waveguide windows situated in the input and output feeds to the accelerator. Input and output mode transformers connect the rectangular waveguide feeds to the circular accelerator waveguide and permit the full flow of microwave power with negligible reflection.

2. MAGNETRON

2.1 GENERAL

The tunable magnetron type M5125 provides the microwave pulsed power and is capable of a peak output power of 2 MW. It operates at a nominal frequency of 2998 MHz and is tuned to the required operating frequency by a built-in tuning plunger which is connected to a tuning motor assembly, the tuning motor being controlled by the automatic frequency control (AFC) system. The power delivered by the magnetron is determined by the magnetic field of its associated magnet and the voltage pulse applied to its cathode.

The magnetron cathode, which is heated indirectly by a filament, is pulsed negatively with voltages in the 40-45 kV range from the Modulator, from which pulse currents up to 100 A are drawn. The magnetron incorporates an output window through which the generated microwave power passes into the rectangular waveguide via the transition section and high-power isolator.

The power supply for the magnetron filament heater is designed to vary the amount of power supplied in accordance with the mean power input to the magnetron. This requirement is specified by the magnetron manufacturer and is due to the fact that the cathode is also heated by electron back-bombardment, the heating effect increasing with increasing cathode mean current. The Magnetron Filament Supply, which is described in text 4, is designed to maintain the cathode temperature constant, independent of input power level.

2.2 MAGNETRON REQUIREMENTS

The magnetron requirements are as follows:

(1) Heater voltage at magnetron terminals with no cathode input power: 8.5 ±0.5 volts (Ph.A/B); 9.0 ±0.1 volts (Ph.C).

For checking and adjustment procedure, see Magnetron Filament Supply in text 4.3.

(2) Water-cooling flow rate (Ph.A): 5.7 litres/min (1.25 gall/min).
Water-cooling flow rate (Ph.B/C): 6.8 litres/min (1.5 gall/min).

Check that the flow rate through the magnetron block is at least 4.5 litres/min (1 gall/min).

(3) Magnetic field strength: 155 ±2.5 mT, (1550 ±25 gauss), measured in situ at the centre of the gap between the magnetron magnet pole-pieces. Probe area should not be greater than 5 cm^2.

Check that the value for the magnetic field lies inside the specified limits. If it does not, the magnetron performance will be affected adversely.

(4) The North pole of the magnet (marked 'N') must be adjacent to the cathode terminal (marked 'C').

2.3 MAGNETRON FREQUENCY

Magnetron frequency range: 2994 to 3002 MHz.

Check that the magnetron operates over the specified frequency range as follows:

(1) At the patching panel on the MCC (Level 1) connect RF MON to TP1 or TP2.

(2) Connect a suitable wavemeter (covering the range 2990 to 3010 MHz) to the appropriate socket on the engineer's panel of the TCC, and set up the wavemeter to measure frequency, (e.g. in conjunction with an oscilloscope).

(3) Set the AFC switch on the engineer's panel to MAN for manual control of magnetron frequency. Switch-on H.T., then operate the AFC (+) switch to increase the magnetron frequency until AFC LIMIT is illuminated, indicating that the upper frequency limit has been reached. Note this frequency.

(4) Operate the AFC (-) switch to decrease the magnetron frequency until AFC LIMIT is again illuminated, indicating that the lower frequency limit has been reached. Note this frequency.

(5) Check that the two limiting frequencies cover the specified range at least.

The magnetron frequency can be set manually or automatically controlled by the AFC system. Check the operation of the AFC system as detailed in text 7.2.

2.4 MAGNETRON PARAMETERS

Check the following magnetron parameters using the procedures for the Modulator discharge given in Chapter 6 : Modulator System.

(1) Magnetron current pulse amplitude: 95 ±5 A. The pulse amplitude must not exceed 100 A.

(2) Magnetron current pulse width: 4.0 microseconds at 50% amplitude.

(3) Magnetron voltage pulse amplitude: 44 ±2 kV. The pulse amplitude must not exceed 47 kV.

(4) Rate-of-rise of voltage pulse at 90% amplitude: 110 kV/microsecond (typical). The rate-of-rise measured at 80-100% amplitude must not exceed 120 kV/microsecond.

3. CHANGING THE MAGNETRON

CAUTION

DURING MAGNETRON CHANGING OPERATIONS, TAKE CARE TO PREVENT ANY FERRO-MAGNETIC MATERIAL COMING IN CONTACT WITH THE MAGNETRON MAGNET AS THIS MAY IMPAIR THE FIELD STRENGTH OF THE MAGNET.

3.1 EQUIPMENT

The following items are required:

- 10 mm A/F, open-ended spanner (non-magnetic);
- 7/16 in. A/F, open-ended spanner (non-magnetic);
- 5/8 in. A/F, open-ended spanner (non-magnetic);
- 15/16 in. A/F, open-ended spanner (non-magnetic), or an ordinary adjustable type if used with care;
- Screwdriver for 2BA screws;
- Earthing rod;
- APIEZON 'L' Grease.

3.2 MAGNETRON REMOVAL

Proceed as follows:

(1) Rotate the Gantry to 180°, so that the radiation head is at its lowest position.

(2) Switch off the electrical supplies via the MAINS contact breaker on the MCC.

(3) Remove the appropriate panel on the Gantry to obtain access to the magnetron.

(4) Turn off the water supply to the magnetron by closing (turning

clockwise) the two taps in the water pipes connected to the magnetron.

(5) Release the pressurised air from the rectangular waveguide through the filter on the air release tap located near to the pressure switch SN. If failure of the high-power isolator is suspected, adopt suitable safety precautions (see text 5.4).

(6) Disconnect the three tuning-motor 24 volts d.c. supply leads from the connector TS-12 on the side of the tuning drive assembly.

Remove the two M6 x 20 hex, nuts and bolts, with plain and crinkled washers, holding the tuning drive assembly to the top flange of the magnetron.

Lift the assembly clear of the magnetron tuner.

(7) Disconnect the two water pipes from the magnetron by unscrewing the two 1/4-inch BSP water unions on the magnetron body; also slacken the 12 mm x 1/2-inch BSP, union adaptors at the other ends of the pipes, at the two taps, to allow the pipes to be swung clear.

(8) Take out the four M4 pan-head screws and remove the earthing plate with Perspex shield, screening the e.h.t. area around the magnetron terminals.

(9) To assist in their subsequent replacement, note the positions of items retained by the two Allen screws at the magnetron cathode terminals. Remove the two Allen screws. Unclip the large resistor R1 and remove together with the PWB containing C4.

(10) Remove the eight 1/4-inch UNF nuts and bolts, with plain and crinkle washers, securing the magnetron output (lower) flange to the adjacent transition section, along with the earth braid.

(11) Remove the two M6 nuts and screws, with spring and plain washers, securing the magnetron-body flange to the support plate. Loosen the two lower screws in the support bracket and slide the support plate clear of the flange.

(12) Lift the magnetron clear, leaving the O-ring seal for the output flange in place in the transition section.

3.3 PREPARATION OF NEW MAGNETRON

Prepare the replacement magnetron as follows:

(1) Examine the glass r.f. window and ensure that it is clean and free from loose particles, etc.

(2) Test for heater continuity and check the action of the tuner mechanism for smoothness.

(3) Unscrew the drive pin from the tuner of the newly-removed magnetron.

Fit this drive pin to the tuner of the replacement magnetron.

3.4 MAGNETRON REFITTING

Fit the replacement magnetron as follows:

(1) Remove and examine the O-ring seal on the transition section; if necessary, obtain a new ring of approved type. Wipe clean the O-ring groove in the transition section, then replace the O-ring, lightly smeared with APIEZON 'L' grease, in the groove.

(2) Insert the replacement magnetron between the magnet pole-pieces and lower the magnetron on to the transition section. Take care that the O-ring is not disturbed in the process.

(3) Insert the eight 1/4-inch UNF bolts in the output flange, then fix washers and nuts to all six fixings and tighten them evenly, except for the one to which the braided earth-lead is to be attached (step (7)).

(4) Refit the support plate to the magnetron-body flange and retighten the screws securing the plate to its bracket.

(5) Replace all magnetron cathode terminal items removed at step (9) of 3.2.

(6) Refit the shield with its Perspex side facing inwards and its metal side against the inside face of the brackets, and secure it as before.

(7) Take the free end of the metal earth braid from the pulse transformer outside the shield plate and attach it to the same magnetron flange fixing bolt, with washers and nut, as originally used.

(8) Position the tuning drive assembly over the magnetron tuner, taking care to engage the slot in its circular drive plate with the tuning-drive pin on the magnetron, then fasten the assembly to the top flange of the magnetron using two 1/4-inch UNF bolts.

(9) Connect the two water pipes and tighten the water unions at both ends. Open the two water taps.

(10) Check that the air release tap is closed, then pressurise the waveguide to 2.1 bar (30 p.s.i.) via the Schrader type valve adjacent to the air- pressure gauge. Do not exceed 2.2 bar (32 p.s.i.).

(11) Turn on the water and switch on the electrical supplies again. Ensure that the Water Cooler is operating, then check the magnetron water connections for leaks.

(12) Ensure that the magnetron tuner turns smoothly and symmetrically when operated by the drive shaft of the tuner driver assembly. This requires the assistance of another person to operate the AFC manual

control on the engineer's panel. Check also that the magnetron is aligned symmetrically between the pole-pieces of the magnet.

(13) Replace the Gantry access panel, then carry out the magnetron running-in procedure as in 3.5.

3.5 RUNNING-IN A NEW MAGNETRON

After fitting a new magnetron to the Linac, it is important to 'run-in' the magnetron properly as this will greatly enhance its life and will also avoid stressing other parts of the microwave system. Before commencing to run-in the magnetron ensure that its requirements (text 2.2) are met. Always run-in by starting at the lowest available p.r.f. and gradually increase up to the maximum rate. The detailed procedure is as follows:

Set the lowest p.r.f. then switch-on H.T. Check the magnetron current pulse amplitude and adjust it to 95 ±5A using the Clipper Control RV1.

Increase the p.r.f. progressively up to the maximum rate and ensure that the magnetron runs smoothly for several minutes at each p.r.f. without overload trips occurring. If the Reverse Diode Overload operates at any time during this run-up (R. DIODE OVERLOAD indicator on engineer's panel of the TCC flashes), leave the magnetron operating at the set p.r.f. until the overloads cease. However, if the magnetron sparks repeatedly, decrease the p.r.f. or switch the p.r.f. selector to OFF for several seconds to allow the magnetron to recover; then proceed as before.

When the magnetron is operating satisfactorily at the maximum p.r.f, check the radiation dose-rate. If it is less than the normal dose-rate increase the magnetron pulse current slightly using Clipper Control RV1 until this dose-rate is obtained; take care not to exceed 100 A for the maximum current pulse amplitude.

If the performance of a new magnetron is unsatisfactory and it cannot be run-in properly, first consult MEL Service Department (see Preliminary page P.2 for details) before returning the magnetron to the manufacturer or his authorised supplier.

4. MAGNETRON FILAMENT SUPPLY

Circuit diagrams:

- Magnetron Filament Supply : 4513 326 3900, Gp.130, Sht.1.
- Control board PWB62-A : 4513 326 6100, Gp.130, Sht.1.
- Interlocks : 4513 329 0010, Gp.130, Sht.2.

4.1 BRIEF DETAILS

The Magnetron Filament Power Supply is located in the Gantry and provides the d.c. power for the heating filament of the magnetron cathode. During operation of the magnetron the temperature of the cathode is raised by electron back-bombardment. To compensate for this heating effect, which increases as the magnetron mean power level is increased, the magnetron filament temperature

needs to be reduced by the same amount. Since the modulator mean current is proportional to the magnetron mean power, the H.T. current level is used as the control signal for automatically regulating the output voltage of the Magnetron Filament Supply in suitable steps to maintain the magnetron cathode at a constant temperature. The control voltage from H.T. current monitor R2 (see 4513 329 2000) is fed to the control board PWB61-A which in turn controls the state of relays RL39-A and RL39-B in the Magnetron Filament Power Supply. The p.r.f. rates at which the relays become de-energised to reduce the a.c. voltage applied to rectifier X2 are as follows:

PRF	RL39-A	RL39-B
50/60	ENERGISED	ENERGISED
150/180	ENERGISED	DE-ENERGISED
300	DE-ENERGISED	DE-ENERGISED

4.2 CIRCUIT DESCRIPTION

An overall appreciation of the magnetron filament control circuit is given by Fig. 2. 240 volts a.c. is supplied to the primary of transformer T2 in the Magnetron Filament Power Supply via the contacts of RL39-A. The output from the secondary of T2 is fed from one of two tapping points, the appropriate tapping being selected by the change-over contacts of RL39-B. This output is applied to the full-wave bridge rectifier circuit X2 and smoothed by C7; it is then fed out to the magnetron heater terminals via the bifilar windings of the pulse transformer.

The control signal for the automatic change in output of the Magnetron Filament Power Supply is taken from the H.T. current monitor resistor R2 in the earth return path of the H.T. Supply. This signal is applied to the control circuits which are located on PWB61-A in the MCC. At a p.r.f. of 50/60 p.p.s., the control signal to pin 18 of PWB61-A is below the threshold level set by ZD1, therefore, transistors TR1 and TR2 are conducting, and the associated relays RL61-A (150 p.p.s.) and RL61-B (300 p.p.s.) are energised. Thus relay RL39-A on the Magnetron Filament Power Supply is energised and the associated contact in T2 primary is closed. Relay RL39-B is also energised and so connects the higher voltage tapping on T2 secondary to the full-wave bridge rectifier X2; this results in an output voltage of about 9 volts d.c. at the magnetron terminals.

At 150/180 p.p.s. operation, the voltage control signal is sufficiently negative to cause ZD1 on PWB61-A to breakdown, and so cut-off TR1 and de-energise RL61-A. Thus the contacts of RL61-A open and de-energise RL39-B on the Magnetron Filament Power Supply. As a result the contacts of RL39-B change-over and connect the lower voltage tapping on T2 secondary to the full-wave bridge X2, resulting in an output of about 5 volts d.c. at the magnetron terminals.

At 300 p.p.s operation, the control signal is sufficiently negative to cause ZD2 on PWB61-A to break down, and so cut-off TR2 and de-energise RL61-B. Thus the

contacts of RL61-B open and de-energise RL39-A on the Magnetron Filament Power Supply. This causes contacts of RL39-A in T2 primary circuit to open, so the output voltage of the supply falls to zero.

An under-voltage protection circuit is fitted to prevent damage to the magnetron when it is operated at 50/60 or 150/180 p.p.s. On PWB61-A, relay RL61-B is energised for 50 to 180 p.p.s. operation, and the corresponding magnetron filament voltage is sampled and applied via a contact of RL61-B to ZD4 on PWB61-A. As a result, ZD4 breaks down and cuts off TR5, thereby causing RL61-C (Magnetron Filament Fault) in TR6 collector to become energised; contact RL61-C then complete part of the main interlock chain.

If however, the voltage from the Magnetron Filament Power Supply is too low, ZD4 does not break down and TR5 conducts. As a result, TR6 is cut-off and RL61-C is de-energised; consequently contact RL61-C changes over, breaking the main interlock chain and lighting the MAG FIL FAULT indicator on the TCC engineer's panel. For 300 p.p.s. operation, RL61-B becomes de-energised and contacts RL61-B change-over. This results in -15 volts being applied to ZD4 which breaks down and cuts off TR5, thereby causing the Magnetron Filament Fault relay RL61-C to become energised and complete the interlock, even though the magnetron filament voltage is zero.

4.3 SETTING-UP THE MAGNETRON FILAMENT SUPPLY

With SUPPLIES switched-on at the engineer's panel but H.T. switched off, proceed as follows:

(1) Connect a multimeter, set to 10 volts d.c., directly across the heater terminals of the magnetron in the gantry and check that the heater d.c. voltage is 8.5 ±0.5 (Ph.A/B) or 9.0 ±0.1 (Ph.C). If not, adjust the heater voltage to this level by means of the tapping points on the Magnetron Filament Power Supply transformer T2.

(2) On the engineer's monitor at the TCC, check that the MAG FIL V display corresponds to the voltage indicated on the multimeter. If not, adjust RV1 on PWB76-LL in the TCC until the display corresponds.

(3) Remove the multimeter from across the magnetron heater terminals, then switch-on H.T.

(4) Set the PRF selector to positions 1 (50/60 p.p.s.), 2 (150/180 p.p.s.) and 3 (300 p.p.s.) in turn and note the MAG FIL V display on the engineer's monitor at each pulse rate. Check that the automatic decrease of magnetron filament voltage with H.T. applied is as shown below.

PRF	MAG FIL VOLTS	
	Ph.A/B	Ph.C
50/60	8.5 ± 0.5	9.0 ±0.1
150/180	5.0 ± 0.5	5.0 ±0.5
300	0	0

Check the operation of the under-voltage protection circuit as follows:

(1) Remove the voltage output of the Magnetron Filament Power Supply, e.g. by switching-off MAG FIL circuit breaker on the MCC. Check that MAG FIL FAULT is indicated on the TCC engineer's panel in this condition.

(2) Press the H.T. ON switch and ensure that it is impossible to switch-on the machine in this condition.

(3) Switch-on the output of the Magnetron Filament Power Supply and check that the MAG FIL FAULT indication is extinguished.

5. WAVEGUIDE

5.1 RECTANGULAR WAVEGUIDE

The microwave power generated by the magnetron is launched through the output window into a transition section (converting the waveguide from circular to rectangular section) and then passes through a high-power isolator which protects the magnetron operation from load effects by offering a high impedance to reflected power. The isolator is connected to a 90°-bend section which carries an r.f. probe for a.f.c. and monitoring purposes, together with a pressure gauge, pressure switch, pressurising valve, air exhaust tap and air filter. The 90°-bend section is connected via a waveguide window to the input mode transformer section which feeds the microwave power to the gun-end of the accelerator; this section carries the pumping port for the ion pump and also the vacuum tap. At the output-end of the accelerator, residual microwave power is extracted by the output mode transformer and fed out via a 90°-bend section and waveguide window to an air-cooled dry load, where it is absorbed without reflection.

The rectangular waveguide sections on the magnetron and load sides of the waveguide windows are pressurised with dry air to 2.1 bar in order to prevent r.f. breakdown in the waveguide at the power levels used. The accelerator sides of the waveguide windows are evacuated to a pressure less than 10^{-5} torr. The mode transformers are used to launch the microwave power into the accelerator and to extract it at the output end; each mode transformer incorporates a tuning plunger for matching purposes.

5.2 ACCELERATOR

The accelerator consists of a cylindrical copper waveguide with copper irises inserted along its length at defined intervals to form a series of cavities, each iris having a circular aperture through which the electrons can pass. The microwave power generated by the magnetron is launched into the accelerator waveguide by the input mode transformer and is propagated as a travelling wave through the accelerating structure. The pulses of electrons emitted from the gun are injected through a hole in the centre of the input mode transformer and are accelerated by the axial electrical field component of the waves. The wave velocity and the amount of energy transferred to the electrons are governed principally by the accelerating guide radius and the radius of the iris apertures, although the iris pitch and thickness also contribute.

In the first part of the accelerator waveguide (bunching section) the phase velocity of the travelling waves matches the velocity of the electrons injected by the gun. Electrons captured by the travelling waves are formed into bunches, one bunch per wave, and the wave velocity and electron velocity rapidly increase to near the velocity of light. In the rest of the accelerator waveguide (relativistic section), the electron velocity increases only slightly and the energy gain results mainly in a relativistic increase in mass.

The microwave power losses in the accelerator are due to energy transfer to the electron beam and resistive losses in the accelerator waveguide structure (copper loss). The residual microwave power at the end of the accelerator waveguide is extracted via the output mode transformer and dissipated in the air-cooled dry load, while the electron beam passes straight on through a hole in the centre of the output mode transformer drift tube. The accelerator is water-cooled and is maintained at high vacuum (less than 10^{-5} torr).

5.3 ACCELERATOR PERFORMANCE

The accelerator is adjusted for optimum performance in the factory. If this performance falls off, and the r.f. match of the accelerator waveguide is suspected as the cause, it will be necessary to check the voltage standing-wave ratio (VSWR) of the accelerator. This procedure requires special equipment, however, and MEL Service Department should be consulted before a VSWR check is attempted (see Preliminary page, P.2).

5.4 ACTION IN CASE OF FAILURE OF HIGH-POWER ISOLATOR

First, it must be emphasised that failure of the high-power isolator is an extremely rare occurence. Should it occur, a likely indication will be inability to operate the Linac due to prolonged and serious electrical breakdown in the rectangular waveguide. However, this condition can be caused also by faults in other components, so it is not necessarily an indication of isolator failure.

The isolator contains small slabs of beryllia ceramic (pale blue material) and also pieces of ferrite material which should be attached to the waveguide walls.

WARNING

THESE SLABS CAN BE HANDLED WITHOUT ANY RISK OF TOXICITY PROVIDED THAT A FEW SIMPLE RULES ARE OBSERVED. HOWEVER, A TOXIC HAZARD ARISES IF DUST FROM THE MATERIAL IS INHALED, AND THIS MAY RESULT IN A SERIOUS RESPIRATORY DISEASE. IT IS ALWAYS A WISE PRECAUTION TO HANDLE BERYLLIA PARTS WITH GLOVES OR SIMILAR PROTECTION IF THERE ARE ANY CUTS ON THE HANDS.

In the case of failure of the isolator, it is possible that the slabs of beryllia have broken into small pieces. The recommended procedure if damage is suspected is as follows:

(1) Release the pressurised air or nitrogen in the rectangular waveguide through the air filter on the exhaust tap in the gantry.

(2) Carefully remove the magnetron and the transition section.

(3) Inspect the isolator for signs of detached or broken ceramic material. If found, put on impervious rubber gloves and a simple surgical mask. In general, detachment of a beryllia slab is unlikely to result in a dust hazard. However, if the slab has been fractured, it must be assumed that some dust has been generated.

(4) Remove the isolator and cover both ends with plastic material. Place the component in a plastic bag together with any loose pieces of ceramic. Do not handle the ceramic with the naked hands. Check other parts of the rectangular waveguide for loose pieces of ceramic and place these with the isolator in the plastic bag.

(5) Wipe the magnetron and adjacent rectangular waveguide with a tissue moistened with alcohol. Put the tissue in a solvent-proof container and dispose of it according to National regulations; if you are unsure of the correct disposal procedure, seek advice.

(6) Dry out thoroughly all waveguide components which have been cleaned.

(7) Seal the polythene bag containing the isolator and beryllia ceramic pieces, then attach a warning label stating:

WARNING

THIS ITEM HAS FAILED IN SERVICE AND IS BEING RETURNED TO THE MANUFACTURER FOR REPAIR. IT IS CONTAMINATED WITH BERYLLIA DUST WHICH CAN BE INJURIOUS TO HEALTH. ON NO ACCOUNT SHOULD IT BE REMOVED FROM THE PLASTIC BAG EXCEPT BY THE MANUFACTURER'S REPRESENTATIVE.

(8) Return the isolator to the Service Department of PRS, using the address given on Preliminary page P-2.

(9) It is unlikely that beryllia dust will have migrated to the other sections of the rectangular waveguide so, provided that the flanges are wiped to remove any possible beryllia dust, a new isolator can be fitted to the waveguide.

(10) Protective clothing and gloves used in this operation should not be washed with other clothing. Washings should be disposed of as advised in step (5). The air filter will not require renewal but, if for any reason it is discarded, it should be sealed in a plastic container and disposed of as in step (5).

6. AFC SYSTEM

6.1 INTRODUCTION

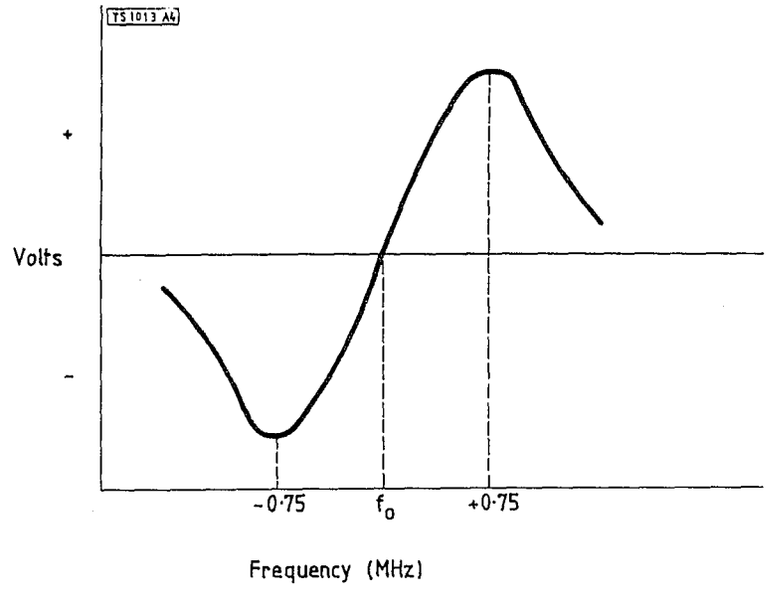
The AFC system automatically controls the operating frequency of the magnetron so as to maintain the required frequency for the accelerator waveguide under any preset condition.

The energy gained by the electrons from the travelling waves in the accelerator waveguide depends on how well the bunches remain in synchronism with the wave, i.e. travel at exactly the same velocity as the wave. The accelerator waveguide is a highly dispersive structure and its propagation characteristics change rapidly with frequency, e.g. for very small changes in frequency, the wave velocity changes. As a result the electrons, instead of remaining in synchronism with the wave and being acted on by the peak electric field, can slip in phase and interact with a lower value of field; this reduces the output energy of the electron beam. In order to counteract this effect, the AFC system maintains the magnetron frequency constant to within 20 kHz of the required operating frequency.

Furthermore, because of internal heating effects in the magnetron, the required AFC tuner position for a given f_o can vary quite widely with p.r.f. Thus if the p.r.f. is changed, the magnetron will commence to oscillate at the wrong frequency; the AFC system must then be relied on to capture the f_o frequency successfully.

6.2 PRINCIPLE OF OPERATION

The AFC system is centred around a frequency discriminator. This consists of two tuned cavities located in a single block and temperature-controlled by the outflowing water from the accelerator waveguide. The two cavities are off-tuned by ±0.75 MHz from the required operating frequency f_o, i.e. one above and the other below f_o by 0.75 MHz. The pulse signals from the high-frequency and low-frequency cavities are detected, then fed to a pulse amplitude discriminator and sample-and-hold detector circuit which produces a d.c. output signal proportional to the difference in pulse amplitudes. This signal is then used, via a power amplifier, to control the magnetron tuning motor so that if the frequency deviates by more than 20 kHz from the required frequency, the motor drives the magnetron tuner sufficiently to correct the frequency error. The AFC system has a frequency discriminator characteristic of the form shown below;



this gives the correction signal applied to the magnetron tuning motor as a function of frequency.

6.3 SYSTEM DESCRIPTION

- System diagram : 4513 329 0002, Gp.130-1

The pulsed microwave power from the magnetron is sampled by an adjustable coaxial probe which is loosely coupled, via a loop, into the wall of the rectangular waveguide. This r.f. signal is distributed through a T-junction to the two cavities and is coupled into each cavity by an adjustable loop. In order to ensure a constant, and approximately equal, r.f. power division at the T-junction, the coaxial leads between the T-junction and cavities are made of a special attenuating type of cable.

An adjustable coupling probe is fitted to the output of each cavity and is joined directly to a detector assembly containing an r.f. diode. The resulting output pulses of about 4 us duration from the two diode detectors are fed out to the pulse amplitude discriminator and detector circuit on PWB76-DD in the TCC. A short length of attenuating cable is used after each diode detector to filter out any remaining r.f. signals.

As the magnetron frequency changes, the amplitude of the output pulse from the two cavities change with respect to each other, e.g. if the magnetron frequency decreases, the output pulses from the low-frequency cavity (LOW) increase in amplitude, while those from the high-frequency cavity (HIGH) decrease in amplitude, and vice versa. PWB76-DD in the TCC accepts these two output pulses, amplifies them and produces a difference output pulse, samples this during that part of the pulse when frequency conditions are stable, and converts the sampled pulse into a d.c. voltage signal proportional to the difference in pulse amplitudes.

Synchronisation of the sample-and-hold detector with the central portion of the detected pulse of r.f. is given by a 15 volts, negative-going, 1 - 3 microseconds pulse from the p.r.f. generator on PWB76-CC, which is delayed by 150/200 microseconds for this purpose. Fine adjustment of the sampling pulse timing is provided by RV3 'Set Delay' on PWB76-DD.

The d.c. error-voltage signal is fed to a power amplifier located on PWB76-EE which is used in the AFC-AUTO condition, to drive the magnetron tuning motor in the appropriate direction so as to reduce the voltage difference to zero, thereby restoring the magnetron frequency to f_o.

A fixed proportion of the a.f.c. error-voltage signal is taken from PWB76-DD to the AFC ERROR contact of selector switch S76-3C for monitoring at the engineer's panel of the TCC.

In order to protect the magnetron tuner mechanism from damage due to its being overdriven, a slipping clutch is fitted. When the mechanical limit of the magnetron tuning range is reached, this causes an associated limit switch to operate, and AFC LIMIT is then displayed on the TCC engineer's panel.

6.3.1 Auto/Manual Frequency Control Selection

The drive signal for the magnetron tuning motor is supplied from two sources: the AFC system or manually controlled ±24 volts supplies. When switch S76-9 on the engineer's panel is set to AUTO, AFC action is obtained as soon as H.T. is switched on; the H.T. Hold relay RL76-DD is energised by this act, and its contacts close, feeding the error signal to the magnetron tuning motor. When H.T. is switched-off, contacts RL76-DD open; this prevents the magnetron being driven off-frequency during standby periods due to drift effects in the amplifiers, etc.

When switch S76-9 is set to MAN, the magnetron tuning motor is manually controlled by the adjacent centre-biased toggle switch from the ±24 volts supplies. Note, however, that in the PREPARATORY position of the key switch on the TCC, AFC operation is automatically selected, independent of the position of the AUTO/MAN switch.

7. SETTING-UP THE AFC SYSTEM

7.1 SUMMARISED PROCEDURE

If the AFC switch on the engineer's panel is set to AUTO, the feedback loop is closed when H.T. is switched-on and the magnetron is then tuned automatically to the particular f_o value set up. If, however, the AFC switch is set to MAN, the magnetron frequency can be adjusted manually. Using this facility, the AFC-ERROR display on the engineer's monitor can be used to monitor the frequency error so that, after tuning manually for optimum performance, any remaining error can be set to zero by adjusting the Set Balance control of the amplitude discriminator. The feedback loop can then be closed by setting the AFC switch to AUTO. The detailed procedure is given below.

7.2 DETAILED PROCEDURE

Proceed as follows, but first check if part 8 of this text applies.

(1) With SUPPLIES only switched-on, set the selector on the engineer's panel to AFC-ERROR. Adjust RV2 on PWB76-DD for zero on the engineer's monitor to obtain the d.c. balance.

(2) At the patching panel on the MCC (Level 1) connect RF MON to TP1. Connect a suitable wavemeter (covering the range 2990 to 3010 MHz) to monitor socket TP1 on the engineer's panel at the TCC.

(3) Set-up a dual-beam oscilloscope and connect the wavemeter to one input. Connect TP1 on PWB76-DD to the other input of the oscilloscope.

(4) Set the AFC switch on the engineer's panel to MAN to obtain manual control of the magnetron frequency. Switch-on GUN and H.T., then manually tune the magnetron for maximum dose-rate. Measure this frequency with the wavemeter and note it; this is the required frequency f_o.

(5) Increase the magnetron frequency to give a peak positive-going signal at TP1 on PWB76-DD (see Fig. 4a); note this frequency. Decrease the magnetron frequency to give a peak negative-going signal at TP1 (see Fig. 4b); note this frequency. The two frequencies should be ±0.75 MHz about f_o. If not, set the frequencies to these values by adjusting the appropriate pair of tuning screws on the cavity block located in the gantry (adjust both tuning screws by equal amounts).

WARNING

DO NOT CARRY OUT THE TUNING SCREW ADJUSTMENTS WITH H.T. SWITCHED ON.

(6) Connect the oscilloscope to TP1 and TP2 on PWB76-DD. Check that the sampling pulse occurs during the central flat portion of the TP1 waveform (see Fig. 4). If not, adjust RV3 on PWB76-DD to move the sampling pulse to the correct position.

(7) Set the magnetron frequency to f_o, then adjust the Set Balance control RV1 on PWB76-DD to give zero for the AFC-ERROR display on the engineer's monitor.

(8) Set the AFC switch to AUTO and check that the frequency remains at f_o. If not, recheck steps (4) to (7).

(9) Manually tune to 0.75 MHz above f_o, then switch to AUTO; note the resulting frequency and dose-rate. Manually tune to 0.75 MHz below f_o, then switch to AUTO; again note the resulting frequency and dose-rate. In both cases the X-ray output should be within 5% of the maximum output obtained manually.

8. R.F. PROBE ADJUSTMENT

If the r.f. probe in the waveguide has been moved for any reason, it will probably be necessary to reset it, and the cavity loop couplings, for correct signal amplitude prior to setting-up the AFC system. Proceed as follows:

(1) Insert a BNC tee-section in series with each coaxial connection to the TCC, i.e. SK76-MM and SK76-NN, and connect the tees to a dual-beam oscilloscope.

NOTE

To give the correct loading conditions, the signals should remain connected to the inputs on PWB76-DD.

(2) Set the AFC switch to MAN. Switch-on H.T., then tune the magnetron frequency manually to give maximum signal on the oscilloscope from one cavity. Adjust the probe depth and rotation to give a pulse amplitude of 0.5 volt approximately, but first, see following 'WARNING'.

WARNING

DO NOT CARRY OUT PROBE ADJUSTMENTS WITH H.T. SWITCHED ON. USE THE ROUTINE : SWITCH-OFF, MAKE ADJUSTMENT, SWITCH-ON.

(3) Tune the magnetron frequency manually to f_o, then adjust the loop coupling on the AFC cavities to give signals of about equal amplitude from the cavities. Disconnect the tee-sections and revert to normal conditions.

9. A.F.C. SERVO-SYSTEM TESTS

9.1 PRELIMINARY MEASUREMENT

Carry out the following measurement for initial record purposes.

Allow time for the Linac temperature to stabilise; also that of the wavemeter, particularly if it has just been brought in from outside. Note the Linac water temperature and the ambient (wavemeter) temperature.

At a p.r.f. of 300 p.p.s., manually tune the magnetron for maximum dose-rate output, then measure and record the magnetron frequency. Note the A.F.C. ERROR reading.

9.2 A.F.C. SERVO-SYSTEM MEASUREMENTS

Test the performance of the a.f.c. servo-system at gantry angles of 0°, 90°, 180° and 270°, in turn, as follows:

(1) Switch AFC to MANUAL and adjust the magnetron frequency for maximum dose rate output.

Note the AFC ERROR monitor reading.

Note the dose rate output reading.

(2) Manually increase the magnetron frequency until a 50%, approximately, reduction in dose rate output is obtained.

(3) Switch AFC to AUTO and note the dose rate output. The a.f.c. shall restore the dose rate output to within 5% of the maximum recorded in (1) above.

(4) Repeat steps (1) to (3), but for a manual decrease in magnetron frequency in step (2).

(5) Calculate the mean value of the dose rate outputs obtained for each gantry angle in steps (3) and (4). Variation of the dose rate output with gantry angle shall not exceed 10% of the mean value, in each instance.

(6) With the gantry at 0°, repeat tests (1) to (4) at the other two p.r.f's. At each p.r.f., the A.F.C system shall restore the dose-rate output to within 5% of the maximum output initially obtained.

* * * * *

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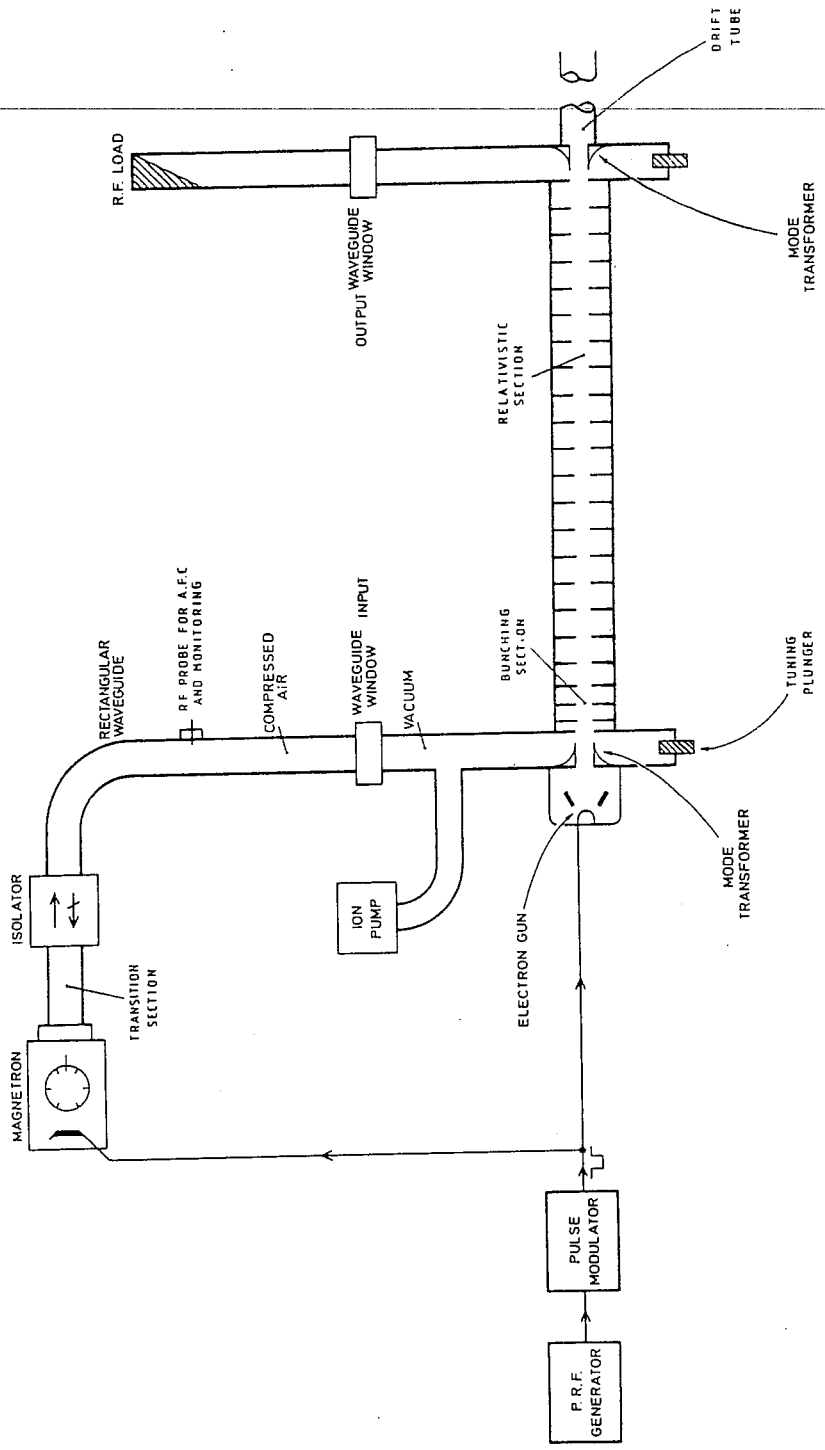


Figure 1: Microwave System, schematic diagram

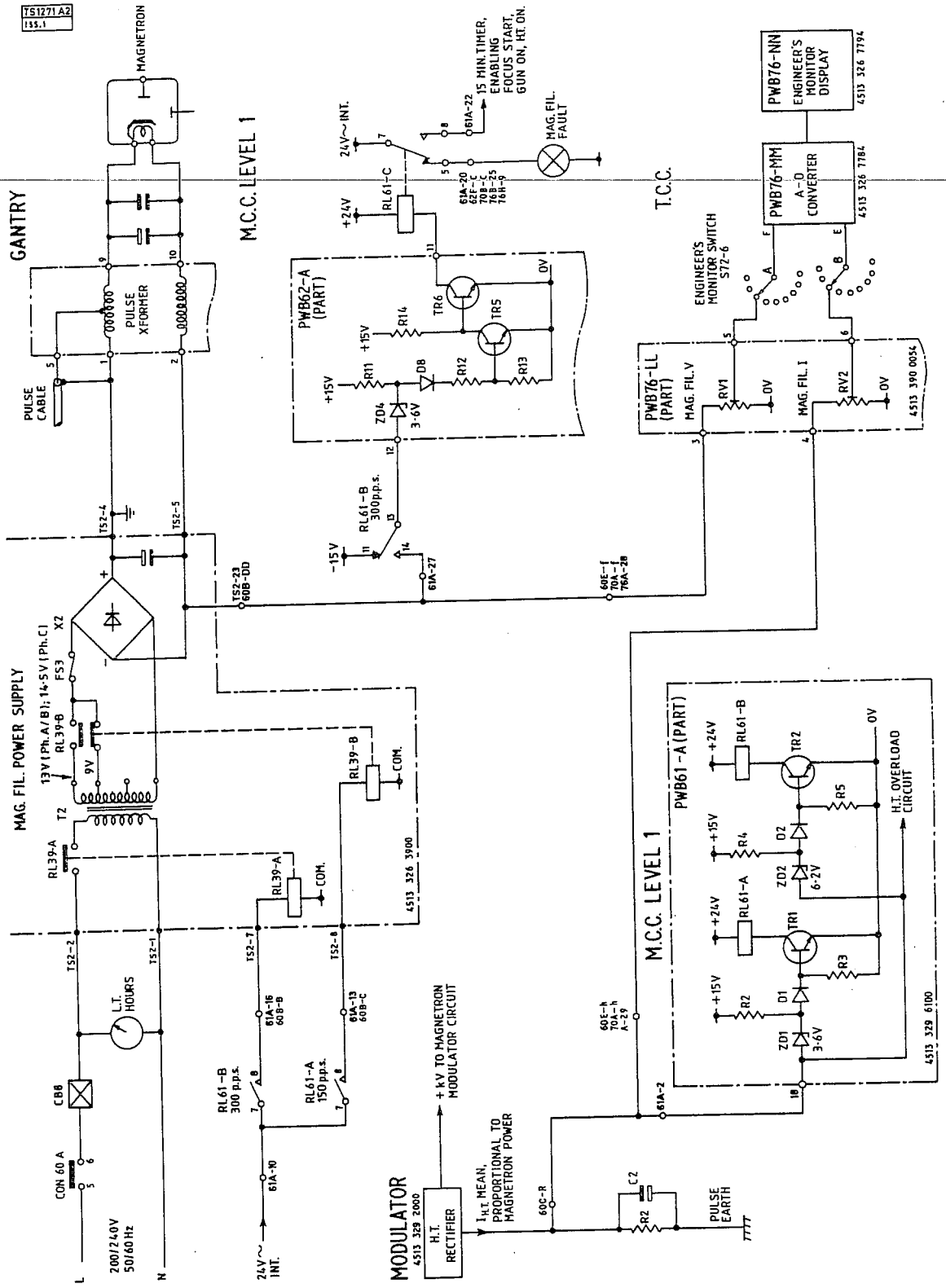
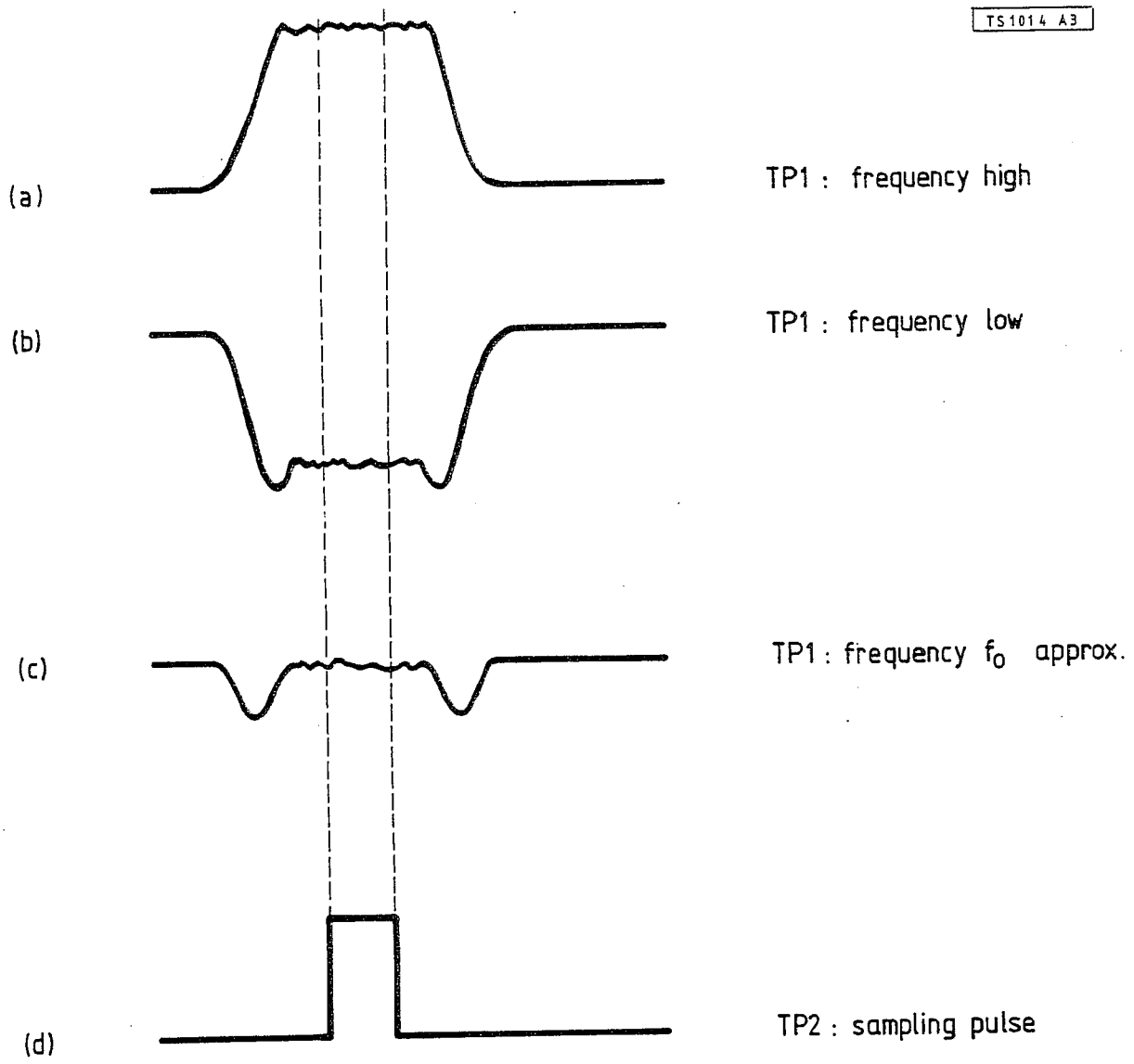


Figure 2: Magnetron Filament Supply, simplified circuit



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Chapter 8: VACUUM SYSTEM

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1. GENERAL INFORMATION

1.1 PREAMBLE

It is necessary to evacuate the Linear Accelerator to a high degree in order to obtain electron emission from the gun and permit the passage of the electron beam down the accelerator waveguide. The degree of vacuum produced also prevents gas breakdown at the microwave power levels used in the accelerator. The ultimate pressure of the Linac vacuum system should be lower than 10^{-6} torr, and the operating pressure should be less than 5×10^{-6} torr; (here operating pressure is the vacuum pressure obtained when the Linac is working under normal operating conditions).

1.2 VACUUM UNITS

Vacuum pressures are measured in the SI unit Pascal (Pa) or the CIPM* approved unit millibar (mbar). In addition they may still be found expressed in the older units torr (torr) or millimetres of mercury (mm Hg). The units are related as follows:

1 Pa = 10^{-2} mbar = 7.5×10^{-3} torr

1 mbar = 10^{2} Pa = 0.75 torr

1 torr = 1 mm Hg = 133 Pa = 1.33 mbar

* Comité International des Poids et Mesures.

1.3 RULES FOR CLEANLINESS

As the pressure in a vacuum system decreases, the effects of outgassing from vacuum components and walls become increasingly important. The amount and rate of gas or vapour evolution is determined by the cleanliness of the vacuum system components, and this affects both the pump-down rate and the length of time to achieve a prescribed vacuum pressure.

Cleanliness is essential for the attainment of high-vacuum conditions. Since almost all solids, liquids and vapours are detrimental to these conditions, they must be eliminated, or be capable of easy removal, from the vacuum system and its components. The following rules therefore should be observed:

- The surfaces of clean vacuum components (i.e. surfaces forming part of the vacuum system) should be touched only with clean tools or protected hands (e.g. nylon gloves).
- Dust and dirt should be removed with a lint-free cloth.
- Finger grease contamination, caused by handling with unprotected hands, should be removed with an approved solvent, e.g. Ligroin petroleum spirit (see Note).

NOTE

Most normal solvents, including alcohols, are unsuitable and their use can result in long outgassing times and poor vacuum pressures.

- Do not use even an approved solvent unless absolutely necessary.
- Store clean vacuum components in a suitable container until required for use; if possible store them under vacuum conditions (e.g. in a bell jar or desiccator).

1.4 VACUUM SYSTEM COMPONENTS

The vacuum system is comprised of the following main components:

- Accelerator waveguide,
- Electron gun,
- Input and output mode transformers,
- Input and output waveguide windows,
- Output drift tube, bending chamber and target/window assembly,
- One ion pump, with associated pumping manifold,
- Vacuum port and tap.

1.5 MONITOR AND CONTROL ARRANGEMENTS

The vacuum system is maintained at a pressure less than 10^{-5} torr by an ion pump at the gun end of the accelerator waveguide. The d.c. power for the pump is provided by the Ion Pump Power Supply on the Gantry. Pressure is monitored by measuring the ion pump current to which it is directly proportional. The VACUUM meter is located at Level 1 of the MCC and is calibrated directly in terms of vacuum pressure (torr). The meter can be unplugged from the MCC and relocated in a jack socket on the engineer's panel of the TCC to enable vacuum to be monitored from there. Also at Level 1 is a printed wiring board carrying the meter calibration components and trip circuits that operate at two levels of vacuum pressure, 10^{-5} and 10^{-4} torr, to give protection against operating under too-high or poor vacuum conditions.

1.6 VACUUM PUMP TROLLEY

The ion pump does not operate at pressures higher than 10^{-2} torr, so an initial evacuation system consisting of a Vacuum Pump Trolley (Fig. 1) is used to evacuate the system from atmospheric pressure to a pressure where the ion pump commences pumping. Once the ion pump has taken over, the Vacuum Pump Trolley is disconnected from the vacuum system. Details of the Vacuum Pump Trolley are given in text 3.

2. VACUUM CONTROL SYSTEM

2.1 BRIEF DETAILS

The vacuum control system consists essentially of the ion pump power supply and two associated trip circuits which inhibit operation of the Linac at two different levels of vacuum pressure, namely: 10^{-5} torr and 10^{-4} torr.

- System diagram : 4513 329 0010, Gp.130, Sht.4

Circuit diagrams:

- Ion Pump Power Supply : 4513 326 3800, Gp.130
- Vacuum Monitoring and Trips (PWB61-L, MCC Level 1) : 4513 302 1022, Gp.130

2.2 ION PUMP POWER SUPPLY

The Ion Pump Power Supply, which is mounted on the Gantry near to the electron gun (see Chap. 2, Fig. 3), provides the high-voltage d.c. supply for the ion pump. The type of ion pump used is the Edwards Sputter-ion pump, type EP1-15, which has a rated pumping speed of 15 litres/second. Since the pressure in the vacuum system is directly proportional to the current flowing in the ion pump, the ion pump current meter, which is located at Level 1 of the MCC, is calibrated directly in terms of pressure (torr). The ion pump current is also applied to trip circuits on PWB61-L which operate at two different levels of vacuum pressure; 10^{-5} and 10^{-4} torr. The Vacuum 10^{-5} trip is incorporated to prevent magnetron operation at pressures higher than 10^{-5} torr, thereby protecting the waveguide windows; the function of the Vacuum 10^{-4} trip is to prevent burn-out of the electron gun filament.

Referring to the circuit diagram, a single-phase 240 volts a.c. mains supply is fed to the primary winding of transformer T1. The secondary is connected to a voltage-doubling circuit consisting of capacitors C1, C2 and C3 and rectifiers D1 to D6, giving an output voltage (unloaded) of approximately 3.5 kV. R.F. choke L2 and capacitor C4 form an r.f. filter to prevent spurious r.f. oscillations in the ion pump from damaging the rectifiers. The positive high-voltage supply is fed out to the ion pump at PL/SK-A via a high-voltage cable. The voltage regulation of the supply is such that the ion pump can be operated under all conditions of vacuum without damage.

The output voltage is nominally 3.2 kV at 500 uA, reducing to 1.5 kV at 30 mA and then falling off rapidly; the short circuit current is about 180 mA. Resistor R53 provides a safety bleed at switch-off.

A relay in the supply guards against the false indication of a high vacuum because of failure of the 240 volts input; if this occurs, the relay is de-energised and feeds a -15 volts signal to actuate the Vacuum 10^{-4} and 10^{-5} Trips (see text 2.4). A zener diode connected across the output terminals TS1-6 and 7 limits the voltage developed across the external load and so protects the vacuum meter from overload.

2.3 VACUUM MONITORING

The vacuum monitoring circuit is contained on PWB61-L at Level 1 of the MCC. The input current from the ion pump power supply is applied to a parallel network comprising R2; R3 and D1; R4, ZD1 and D2; R5 and ZD2; ZD3. This network has a logarithmic response and its output is applied to the VACUUM meter which has a logarithmic scale calibrated in torr; hence the log/log relationship between pressure and ion pump current (see Fig. 7) is maintained. Calibration of the meter is adjusted by means of RV1. The meter plugs into a jack socket on the panel of Level 1 or it can be removed and plugged into a similar socket on the engineer's panel at the TCC to enable vacuum to be monitored from there.

2.4 VACUUM 10^{-5} TRIP

The vacuum trips are also accommodated on PWB61-L at Level 1 of the MCC. The voltage appearing across R2 etc. is smoothed by R6, C1 and applied to the inverting input (pin 2) of operational amplifier IC2 connected as a trigger circuit. The non-inverting input (pin 3) is at a negative voltage determined by potential divider R14, RV3, R15. As pressure increases, the ion pump current increases also, and the voltage across R2, etc. becomes more negative. When the inverting input to IC2 becomes more negative than the non-inverting input, the output from IC2, pin 6, changes state from -15 to +15 volts. RV3 is adjusted so that this takes place when the pressure rises above 2 x 10^{-5} torr.

The voltage change at the output from IC2 is fed to the Equipment Fault Drivers and P.R.F. Inhibit circuit on PWB76-BB in the TCC. Here it operates a gating circuit to provide a P.R.F. Inhibit signal which inhibits the output of the p.r.f. generator (and accelerator output) and provides a VACUUM FAULT indication on the TCC engineer's panel. When the pressure falls to below 10^{-5} torr again, the trip circuit resets and p.r.f. generator output resumes. The operation of the gating circuit in the TCC can be overridden using the VACUUM OVERRIDE switch on the engineer's panel. This is useful during run-up after vacuum system work when frequent operation of the Vacuum 10^{-5} trip could be experienced due to outgassing effects; however, the facility should be used with caution. For a complete description of the circuit on PWB76-BB, see Chapter 5 : Treatment Control System.

2.5 VACUUM 10^{-4} TRIP

The 10^{-4} trip is similar in operation to the 10^{-5} trip. The voltage across R2 etc. on PWB61-L is applied to the inverting input of IC1, and a negative voltage from potential divider R8, RV2, R9 is applied to the non-inverting input. RV2 is set so that when the pressure rises above 2 x 10^{-4} torr, the output from IC1 changes state from -15 to +15 volts. This voltage change is fed to the circuit on PWB76-BB in the TCC. In this case, in addition to producing a fault indication and a p.r.f. inhibit signal, the Vacuum 10^{-4} relay RL76-C on PWB76-AA is de-energised, breaking the H.T. and gun interlock circuits (see Chapter 3 : Interlocks). When the pressure falls below 10^{-4} torr again, the gun and H.T. can be switched on again.

3. VACUUM PUMP TROLLEY

3.1 BRIEF DETAILS

The ion pump on the Linac vacuum system does not operate at pressures higher than 10^{-2} torr, so the Vacuum Pump Trolley is used initially to evacuate the system from atmospheric pressure to a pressure at which the ion pump can commence pumping.

- Schematic diagram : Fig. 2
- Circuit diagram : Fig. 3

3.2 DESCRIPTION

The Vacuum Pump Trolley (Fig. 1) consists essentially of a two-stage rotary pump incorporating a gas ballast facility and having a displacement of 5 m^3 per hour. A foreline trap containing artificial zeolite is fitted to trap water vapour and to prevent back migration of rotary pump oil vapour into the Linac vacuum system. The trolley contains a magnetically-operated air-admittance valve which automatically admits air into the rotary pump when the pump is switched-off, and two manually-operated taps with the following functions:

- Tap A : isolation tap between the foreline trap and the main inlet point.
- Tap B : isolation tap between the rotary pump and the foreline trap.

The trolley carries a switch panel (Fig. 4) for control and monitoring purposes. A Pirani gauge is incorporated in the switch panel for monitoring the pressure, the gauge head being connected into the foreline of the assembly between taps A and B. A flexible pumping line for attaching to the Linac is provided. The various components on the trolley are connected by copper tubing and the demountable joints use O-ring seals in vacuum unions.

4. MAINTENANCE INFORMATION

4.1 VACUUM SEALS

The mechanical joints between the various demountable vacuum components embody vacuum seals. Two types are used on the Linac vacuum system:

- Elastomer O-ring seal (Viton A);
- Knife-edge seals employing copper sealing washers.

Sectional views showing the principles of these seals are given in Fig. 5.

4.2 REMOVAL OF VACUUM COMPONENTS

If any part of the vacuum system requires to be dismantled (e.g. the electron gun for filament replacement) it is first necessary to let the vacuum system up to atmospheric pressure. This is accomplished by opening the tap on the vacuum

port. However, normal atmospheric air contains water vapour and, if this is admitted into the vacuum system, it will result in along pump-down time due to outgassing. To avoid this effect it is advisable to let in dry nitrogen instead of normal atmospheric air; a general procedure for this is given in text 4.5.

4.3 LEAK DETECTION

Leaks in the vacuum system may be either real or virtual. Real leaks are actual holes in the vacuum envelope; virtual leaks are mainly due to occluded gases and vapour within the vacuum system, water vapour being the most common. The normal leak detection techniques employed are described in text 5.

4.4 EVACUATION PROCEDURE

4.4.1 Initial Evacuation of the Vacuum Pump Trolley

Initial evacuation of the vacuum system is carried out with the Vacuum Pump Trolley which is prepared for this duty as follows:

(1) On the trolley (Fig. 1), initially ensure that:

- Isolation Taps A and B are closed, i.e. lever positioned at 90° to line of pipe;
- Gas Ballast Valve is closed, i.e. turned fully clockwise;
- Flexible Pumping Line is closed to atmosphere, i.e. capped;
- Pump oil level is adequate (check sight-glass indication);
- Pirani Gauge Head is connected to Head 1.

(2) Connect the mains lead of the trolley to a suitable mains socket near the Gantry and switch-on.

(3) On the switch panel (Fig. 4) ensure that:

- The two push-button switches (PUMP and HEATER) are switched off, i.e. not illuminated;
- The Pirani gauge INST ON switch is switched-off, the gauge range switch is set to RANGE 1, the 1 torr range, and the gauge head switch is set to the position marked HEAD 1;

NOTE

It is assumed for the purpose of these instructions that the Head 1 socket and corresponding switch position will be used throughout.

(4) Switch-on PUMP to start up the rotary pump; this action automatically closes the air admittance valve.

(5) Open tap B (nearest to the rotary pump) and note the time. After 60 seconds check that the switch on the PIRANI gauge is set to RANGE 1, then switch-on the Pirani gauge INST ON switch, which should light up.

(6) A high pressure indication may be obtained initially on the meter. When the pressure indication has fallen below 0.025 torr, set the switch to RANGE 2, the 25 mtorr range.

(7) The Vacuum Pump Trolley is now fully operational with the rotary pump exhausting the pumping line up to isolation tap A. The pressure indicated on the Pirani gauge meter should be less than 10 mtorr.

NOTE

If the pressure does not fall to 5 mtorr within 10 minutes of the time in step (5) above, it is likely that the foreline trap needs regeneration (see text 4.6).

4.4.2 Linac Evacuation

Proceed to evacuate the Linac as follows:

(1) Remove the side cover from the Gantry to obtain access to the vacuum port and tap. Rotate the Gantry to the 180 degree position.

(2) Ensure that the Ion Pump Power Supply is switched off at the VACUUM circuit breaker CB2 at Level 4 of the MCC.

(3) Ensure that all accessible vacuum joints are correctly made and that the vacuum tap on the vacuum port is closed (i.e. turned fully clockwise).

(4) Remove the dust cap from the vacuum port on the Linac and connect the Vacuum Pump Trolley to the vacuum port by means of the flexible pumping line provided. Make sure that the O-ring is correctly fitted to the vacuum union.

(5) Set the Pirani gauge switch to RANGE 1 (1 torr range), then open tap A on the Vacuum Pump Trolley.

(6) Wait about 2 minutes for the flexible line to be evacuated, then open the vacuum tap on the Linac. Note the time at which this is done. The Pirani gauge meter indication will rise initially above 1 torr, then start to fall again.

(7) When the Pirani gauge meter indication has fallen below 0.025 torr, switch to RANGE 2 (25 mtorr range).

(8) Under normal conditions the Pirani gauge pressure should be less than 10 mtorr after 10 minutes from the time noted in step (6). Significantly longer pumping times usually indicate some abnormality in the vacuum system, e.g. a vacuum leak.

(9) When the Pirani gauge meter reading is less than 5 mtorr, switch-on the Ion Pump Power Supply. Observe the pressure on the VACUUM meter at Level 1. If the indicated pressure remains high (e.g. greater than 8 x 10^{-4} torr), or an immediate indication of less than 10^{-8} torr is obtained, switch-off the Ion Pump Power Supply and allow the Vacuum Pump Trolley more time to evacuate the Linac before switching-on the ion pump again.

(10) Repeat step (9) until the meter indicates a slight decrease in pressure, showing that the ion pump is commencing to pump down the vacuum system.

(11) When the pressure falls to about 5 x 10^{-4} torr, isolate the Vacuum Pump Trolley by closing the vacuum tap on the Linac. If the pressure rises as a result, open the tap again. Repeat this procedure until the tap can be left closed without the pressure rising.

NOTE

During prolonged pump-down at the higher pressures (above 10^{-4} torr), an ion pump can be expected to become hot. In this condition it tends to liberate gas previously absorbed, so that the pumping speed may be reduced. However, it is not necessary to switch-off the hot pump since any gas liberated from it is normally pumped away by the Vacuum Pump Trolley.

(12) Close down the Vacuum Pump Trolley by setting the RANGE switch to position 1 and switching-off the Pirani gauge control unit, closing the two isolation taps A and B, then switching-off the rotary pump. This ensures that the foreline trap is left evacuated, thus preventing the zeolite from absorbing water vapour from the atmosphere.

(13) Disconnect the flexible pumping line from the vacuum port on the Linac and replace the dust caps on the vacuum port and flexible pumping line. Replace the gantry covers.

CAUTION

DO NOT ATTEMPT TO MOVE THE GANTRY UNTIL THE VACUUM PUMP TROLLEY HAS BEEN DISCONNECTED FROM THE LINAC.

(14) Arrange to carry out the regeneration procedure for the foreline trap (see 4.6).

4.5 FILLING THE VACUUM SYSTEM WITH DRY NITROGEN

If it becomes necessary to dismantle any part of the vacuum system, the vacuum system should be filled with dry nitrogen gas since this considerably reduces outgassing effects on the subsequent pump-down.

A cylinder of compressed nitrogen gas (99.9% pure) is required, fitted with a reducing valve incorporating pressure gauges to indicate the cylinder gas pressure and the reduced gas pressure. A gas feedline is provided comprising 2 metres of 0.25 in. (6 mm) bore plastic tubing, one end for connecting to the reducing valve on the gas cylinder and the other end terminated in an adaptor to fit the vacuum port on the Linac.

Proceed as follows:

(1) Ensure that the ion pump is switched-off.

(2) If it is intended to dismantle a vacuum joint, slacken off its securing bolts to facilitate removal when the vacuum system is filled with nitrogen gas at atmospheric pressure.

(3) Open the nitrogen gas cylinder and check the cylinder pressure. Ensure that this is at least 200 lb/in^2 (14 bar).

CAUTION

IF THE CYLINDER GAS PRESSURE IS LESS THAN 200 lb/in^2, IT IS ADVISABLE NOT TO USE THAT PARTICULAR CYLINDER SINCE 'DRY' NITROGEN CAN HAVE AN APPRECIABLE WATER VAPOUR CONTENT UNDER THESE CONDITIONS.

(4) Adjust the reducing valve to give a pressure of 3 to 5 lb/in^2 (0.2 to 0.35 bar). Allow nitrogen to escape for about 30 seconds to dry out any moisture in the gas feedline and expel all air from it.

(5) Remove the dust cap from the vacuum port on the Linac and hold the adapter at the end of the gas feedline against the vacuum port. Slowly open the vacuum tap on the Linac to allow nitrogen to fill the vacuum system. Continue to hold the adapter in place until a slight back-pressure is felt, indicating that the system is filled with nitrogen gas at atmospheric pressure.

(6) Close the vacuum tap on the Linac and the valve on the nitrogen gas cylinder. Replace the dust cap on the vacuum port.

(7) Remove the vacuum component.

NOTE

If the vacuum system has to remain open for more than a few minutes, seal-off the openings to

prevent the ingress of dust and water vapour. If it can be certain that the removal and replacement of a vacuum component will be accomplished quickly and without interruption, a surer method is to bolt the nitrogen gas feedline adapter to the vacuum port and, after the system has been filled, allow the gas to flow continuously from where the vacuum component has been disconnected, but at a reduced pressure of 2 lb/in^2 (0.14 bar).

4.6 REGENERATION PROCEDURE FOR FORELINE TRAP

4.6.1 Explanation

The purpose of the foreline trap in the Vacuum Pump Trolley is to help in obtaining a lower pressure than would otherwise be obtained, by trapping water vapour and other vapours removed from the Linac vacuum system. The trap also prevents oil vapour from the rotary pump entering the vacuum system by back migration. The active element in the foreline trap is artificial zeolite. In order to keep the trap material in an efficient state, it should be regenerated periodically. In particular, it should be regenerated after each evacuation of the Linac by the Vacuum Pump Trolley. In any case, the intervals between regenerating the foreline trap should not exceed six months.

4.6.2 Regeneration Procedure

The regeneration procedure is as follows:

(1) Ensure that:

- the two switches on the switch panel (PUMP and HEATER) are in the OFF position;
- the Pirani gauge is switched-off, the RANGE switch is set to RANGE 1 (1 torr range) and the gauge head switch is set to the position marked HEAD 1;
- the two isolation taps A and B are closed (i.e. levers positioned at 90° to the line of the pipe).

(2) Connect the mains lead of the trolley to a suitable mains socket.

(3) Switch-on PUMP to start up the rotary pump.

(4) Open tap B, then switch-on the Pirani gauge.

(5) Unscrew the Gas Ballast control on the rotary pump (turn counter-clockwise).

(6) Switch on HEATER to energise the foreline trap heater. As the temperature of the foreline trap rises so will the pressure, reaching a maximum value of around 0.6 to 0.8 torr.

(7) Allow this process to continue for several hours until the pressure has fallen to about 0.04 torr.

NOTE

The duration of the heating process will depend upon the extent of the zeolite contamination. Overnight processing is convenient and normally should prove sufficient.

(8) Switch-off HEATER and allow the foreline trap to cool; this will take several hours. Do not switch-off PUMP yet.

4.6.3 Final Check

When the foreline trap is cool, proceed as follows:

(1) Close the Gas Ballast control on the rotary pump (turn fully clockwise).

(2) Switch-on the Pirani gauge. Set the range switch to RANGE 2 (25 mtorr) and check the pressure. The indicated pressure should be less than 7 mtorr.

(3) Switch-off the Pirani gauge.

(4) Close isolation tap B, then switch-off PUMP to stop the rotary pump.

CAUTION

AT NO TIME MUST THE VACUUM PUMP TROLLEY BE USED TO EVACUATE THE LINAC WITH THE FORELINE TRAP HEATER SWITCHED ON OR WITH THE TRAP HOT.

4.7 PIRANI GAUGE

The Pirani gauge used on the trolley is the Edwards High Vacuum PIR II. If a fault occurs on the Pirani gauge, use the table in Fig. 8 as a guide to the possible cause and its rectification. The circuit of the Pirani gauge is shown in Fig. 6.

4.8 ROTARY PUMP

4.8.1 Charactistics

The two-stage rotary pump fitted to the trolley has the following characteristics.

Pumping speed (displacement)	:	5 m^3/hour (3 ft^3/min)
Ultimate vacuum - with gas ballast	:	10 mtorr
- without gas ballast	:	0.2 mtorr

4.8.2 Oil Level

The pump should be kept filled with oil of the type recommended by the manufacturer (currently, Rotary Pump Oil type RP 069), up to the level of the circle in the sight-glass (Fig. 1). To top-up, remove the four cap-head screws from the top of the pump, remove the square cover and the baffle plate beneath to expose the oil chamber. Take care not to damage the gaskets.

4.8.3 Periodic Oil Change

The frequency with which the oil requires changing depends on the use to which the pump is put, but in any case it should be changed at least once a year. Capacity of oil pump is 3 imperial pints or 1.71 litres.

Run the pump for a short period to warm the oil so that it drains easily when the drain plug is removed (Fig. 1).

When the pump is apparently empty of oil, turn the pulley several times by hand or run the motor for about 30 seconds to expel all traces of oil from the mechanism.

If the oil is badly contaminated, flush out the pump mechanism by pouring some fresh oil down the inlet pipe, then rotate the pump mechanism by hand and drain off thoroughly as before.

4.9 ION PUMP

4.9.1 Servicing

The model EPI-15 sputter-ion pump is not demountable, so servicing is on a factory-exchange basis. A pump requiring servicing should be returned, without its magnet, to the Service and Installation Department of MEL at the address shown on Preliminary page P-2.

4.9.2 Ion Pump Power Supply

WARNING

TAKE GREAT CARE WHEN TESTING THIS SUPPLY AS A DANGEROUSLY HIGH VOLTAGE MAY BE PRESENT ON IT.

4.10 SETTING-UP THE VACUUM MONITORING AND TRIP CIRCUITS

The circuit on PWB61-L is set up by using a simulation method as follows:

(1) Switch off the Ion Pump Power Supply by means of the Vacuum circuit breaker CB2 at Level 4 of the MCC.

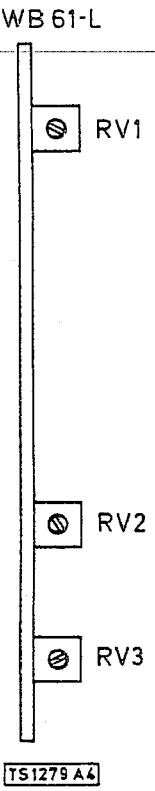
(2) Disconnect the -15 volts lead from pin TSI-5 on the power supply terminal strip and insert a 5 k-ohm variable resistor and a multimeter in the -15 volts line. Adjust the variable resistor for maximum resistance, and select a low current range on the multimeter.

(3) Adjust the variable resistor to give a reading on the multimeter of 5 mA. Reference to Fig. 7 will show that this current is equivalent to a pressure of 2 x 10^{-5} torr.

(4) Adjust RV3 on PWB61-L so that the 10^{-5} trip just operates at this current level, i.e. monitor the voltage at pin 19 of the board and adjust the potentiometer to obtain a voltage change from -15 to +15 volts at this current.

(5) Adjust RV1 on PWB61-L to obtain the correct reading on the VACUUM meter.

(6) Reset the variable resistor to give a current reading of 50 mA. This is equivalent to a pressure of 2 x 10^{-4} torr. Adjust RV2 on PWB61-L so that the 10^{-4} trip just operates, i.e. check for a voltage change from -15 to +15 volts at pin 13.



4.11 VACUUM FAULT INDICATOR CHECKS

To check the operation of the VACUUM FAULT indicator on the engineer's panel of the TCC, repeat the foregoing tests and check that:

(1) At a current of 5 mA, the VACUUM FAULT indicator comes on.

(2) The indicator can be switched off by operating the VACUUM OVERRIDE switch on the engineer's panel.

(3) At the 50 mA current level, the indicator will come on again even if the VACUUM OVERRIDE switch is in the operated position.

4.12 VACUUM TRIP INTERLOCKS CHECK

To check the interlock functions, repeat the foregoing tests while monitoring the output from the P.R.F. Generator in the TCC at coaxial socket SK70-UU. The p.r.f. output should cease when the 10^{-5} trip operates, and should cease again despite the use of the VACUUM OVERRIDE switch, when the 10^{-4} trip operates. Observe also that relay RL-C on PWB76-AA in the TCC operates at the 10^{-4} trip current.

Disconnect the multimeter and variable resistor and reconnect the -15 volts lead to pin TSI-5 of the power supply.

5. LEAK DETECTION TECHNIQUES

Most leak detection techniques involve the observation of pressure changes in a vacuum system following the introduction of a search gas through the leak. The following techniques are those most generally employed for the Linac vacuum system.

5.1 LARGE LEAKS

For investigating large leaks, the Vacuum Pump Trolley is connected to the vacuum system as for initial evacuation. The leak can be detected by applying Ligroin to the suspected area with a small brush and observing any resulting change in pressure on the Pirani gauge. The change in pressure can be either a pressure rise due to search-fluid vapour entering the vacuum system or a fall in pressure resulting from blockage of the leak by the fluid.

A more sensitive arrangement is to search with a halogen gas (e.g. Isceon 12) and observing the pressure rise on a detector attached to a special detector head. For this technique the detector head must be fitted into the vacuum system. Since the Vacuum Pump Trolley is used for evacuation, a suitable place for the detector head is at the vacuum port, the detector head being mounted in a suitable adapter between the end of the flexible pumping line and the vacuum port.

5.2 SMALL LEAKS

At low pressure (less than 10^{-5} torr) small leaks can be detected by means of a suitable search gas (e.g. argon, helium or oxygen) administered by a fine-jet probe. A leak is indicated by a small change in indicated pressure on the vacuum meter due to the decrease in pumping speed when the seach gas is introduced into the vacuum system at the leak point.

The sensitivity of this method can be increased by connecting a digital voltmeter across the Vacuum meter terminals to detect changes in ion pump current due to the search gas.

The mass spectrometer leak detector, if available, is a very sensitive detector of small leaks in a vacuum system. In use, the mass spectrometer is connected to the vacuum system which it evacuates with its own built-in pumping system. Helium gas is directed on to the suspected area by means of a fine-jet probe and a rise in pressure is indicated on the mass spectrometer meter when the probe is positioned directly over a leak.

* * * * * *

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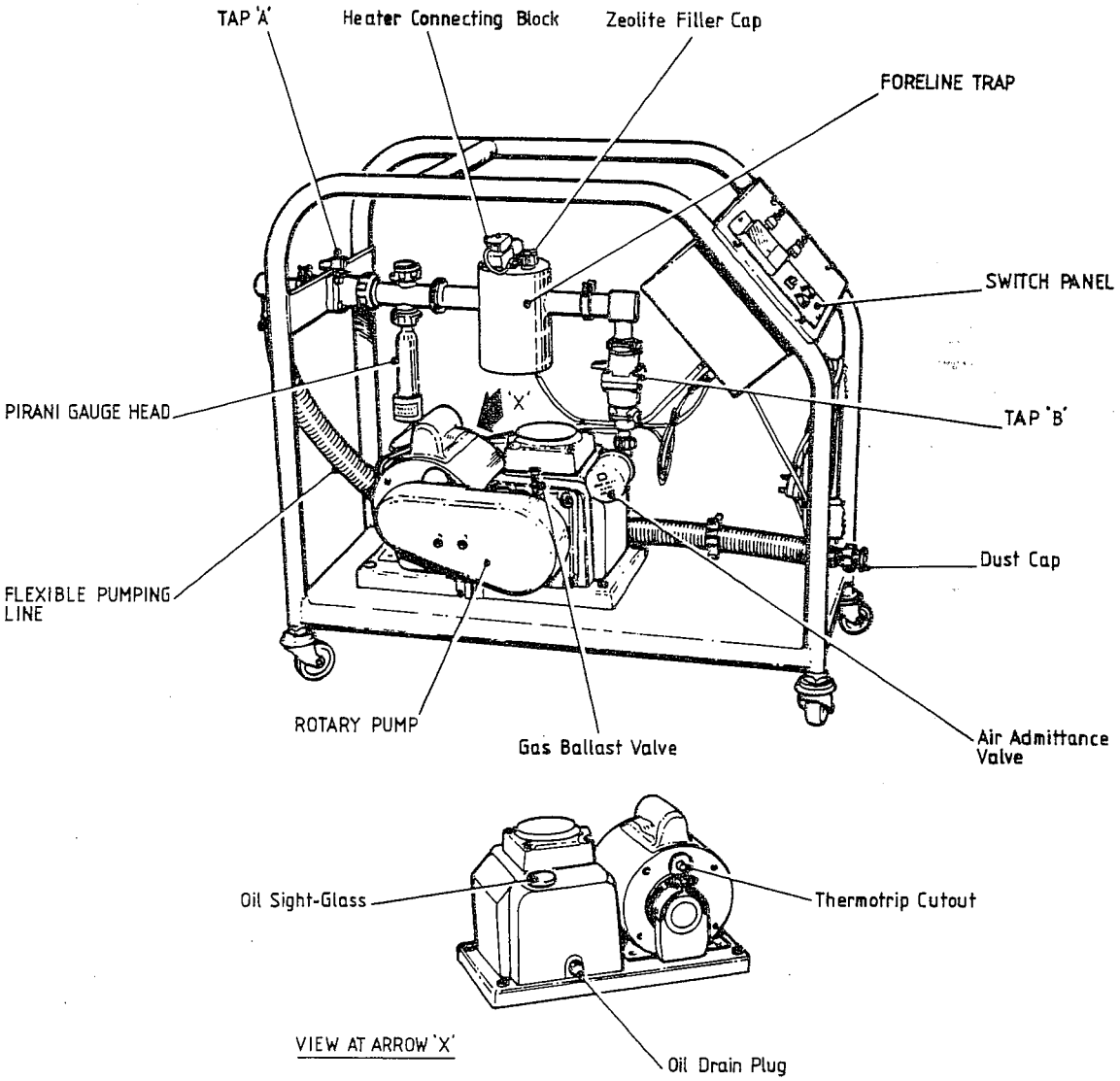


Figure 1: Vacuum Pump Trolley

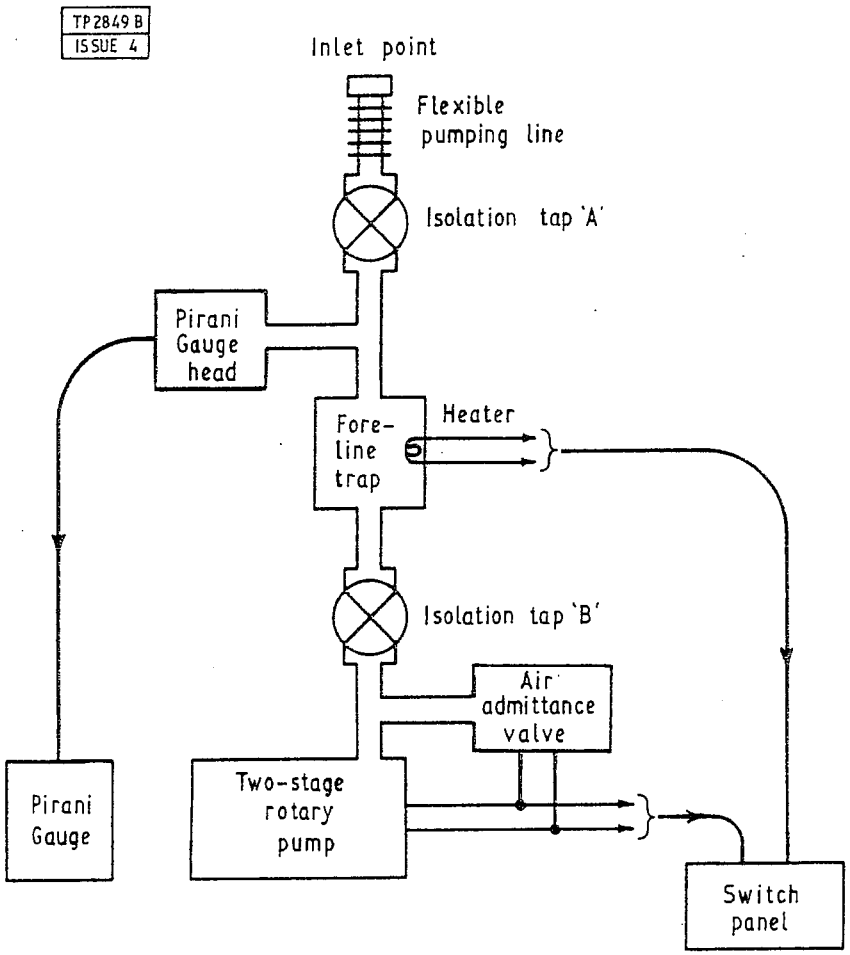


Figure 2: Vacuum Pump Trolley, schematic diagram

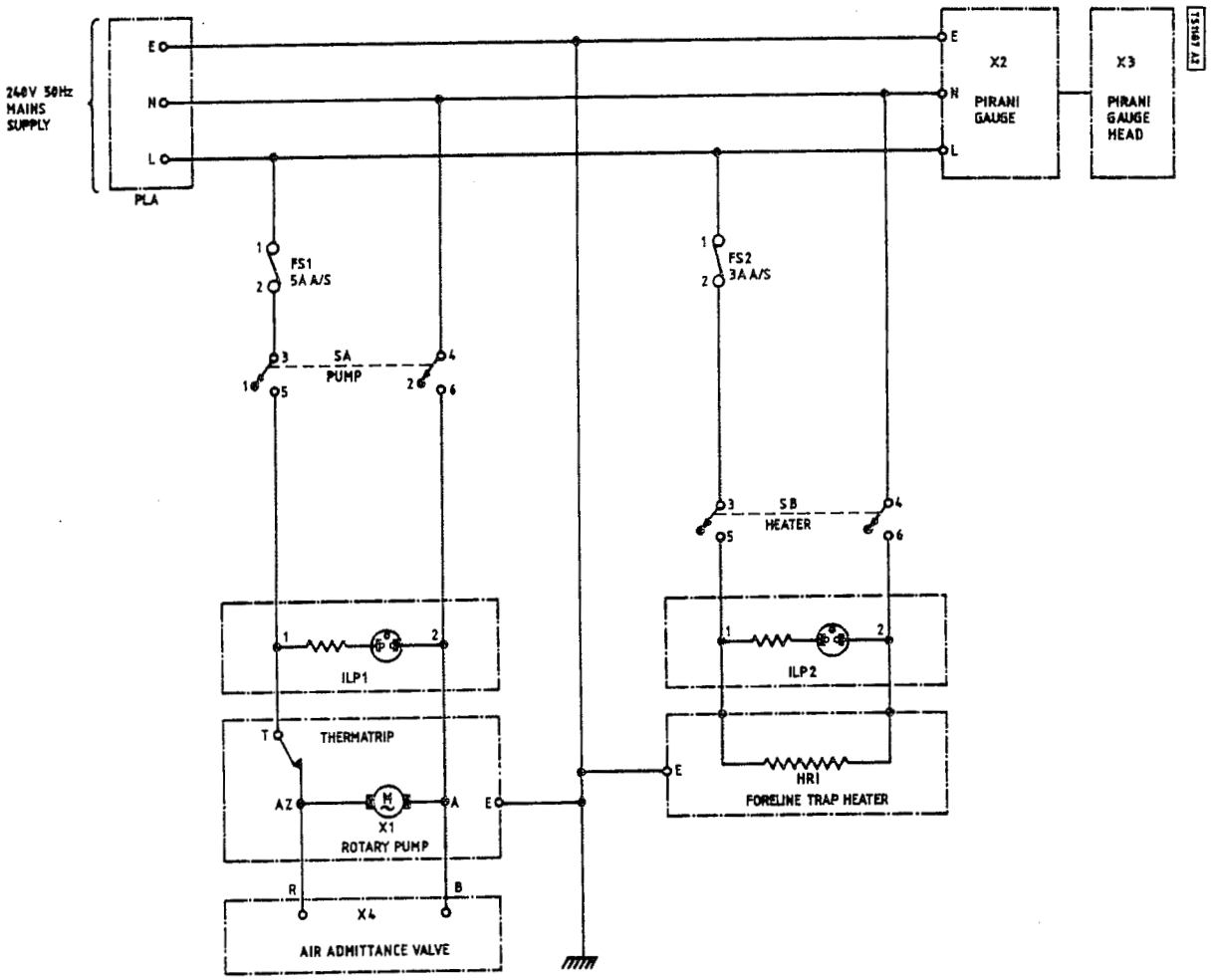
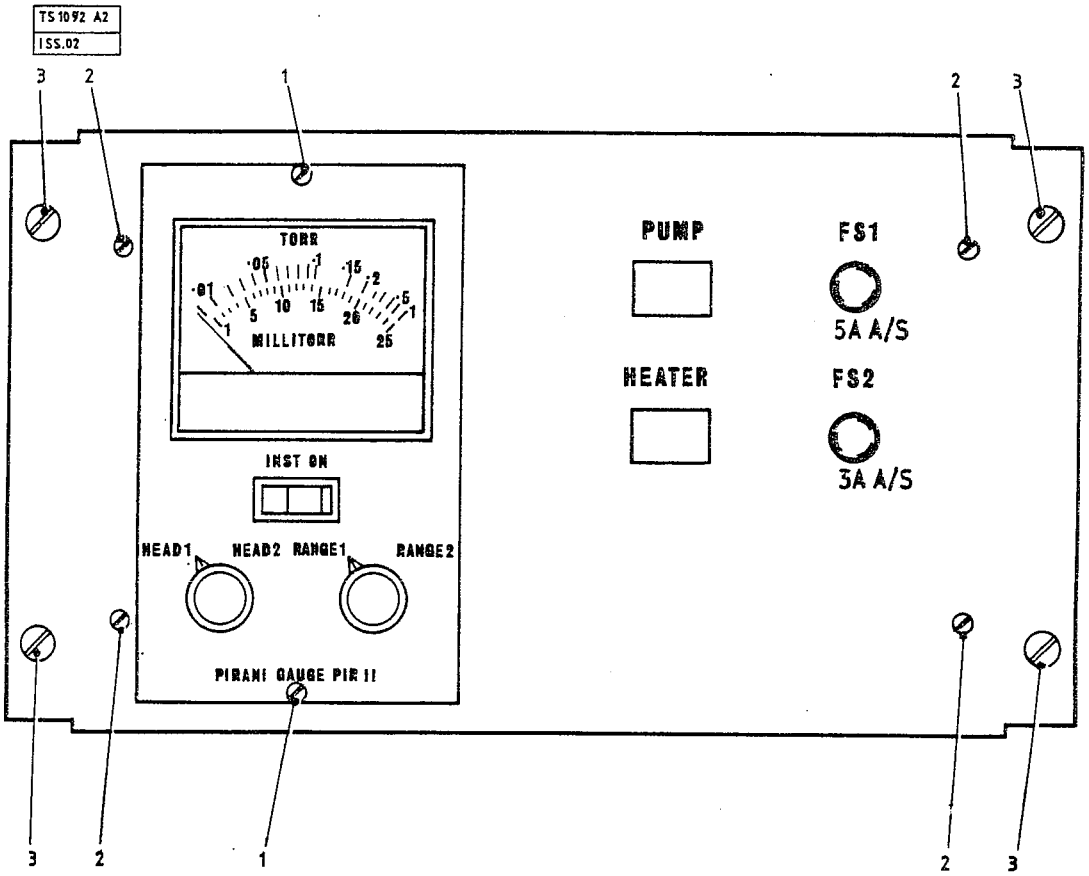
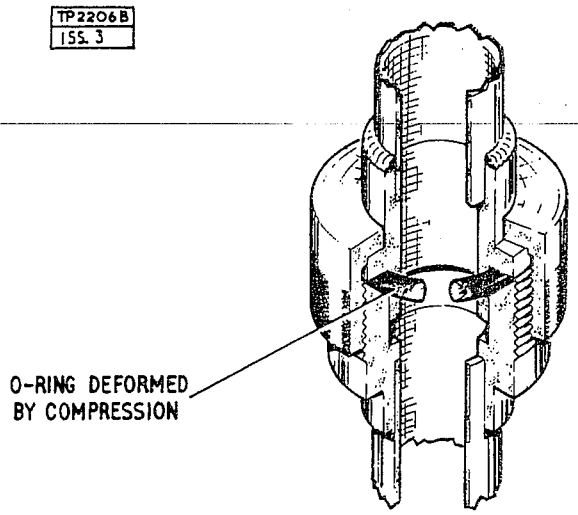


Figure 3: Vacuum Pump Trolley, circuit diagram

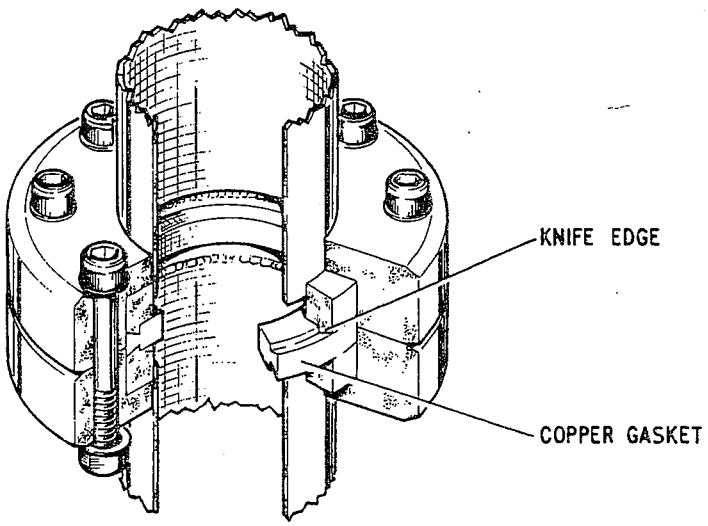


1. Retaining Screws, Pirani Gauge, x 2
2. Retaining Screws, Switch Panel Cover, x 4
3. Retaining Screws, Switch Panel, x 4

Figure 4: Vacuum Pump Trolley, switch panel



(a) O-Ring Seal.



(b) Knife-edge Seal using Copper Gasket.

Figure 5: Vacuum seals, sectional views

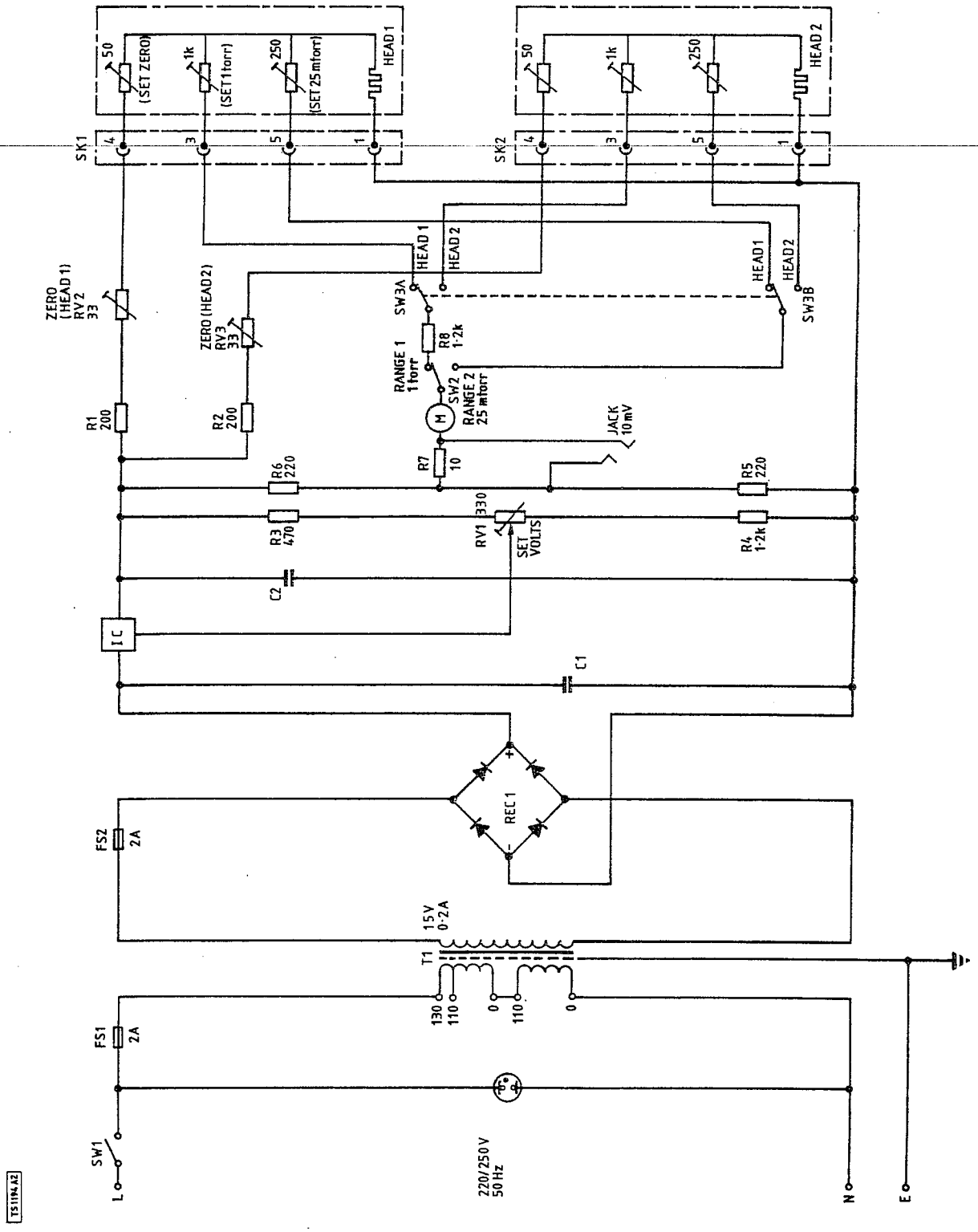


Figure 6: Pirani gauge PIR II, circuit diagram

TP2966B

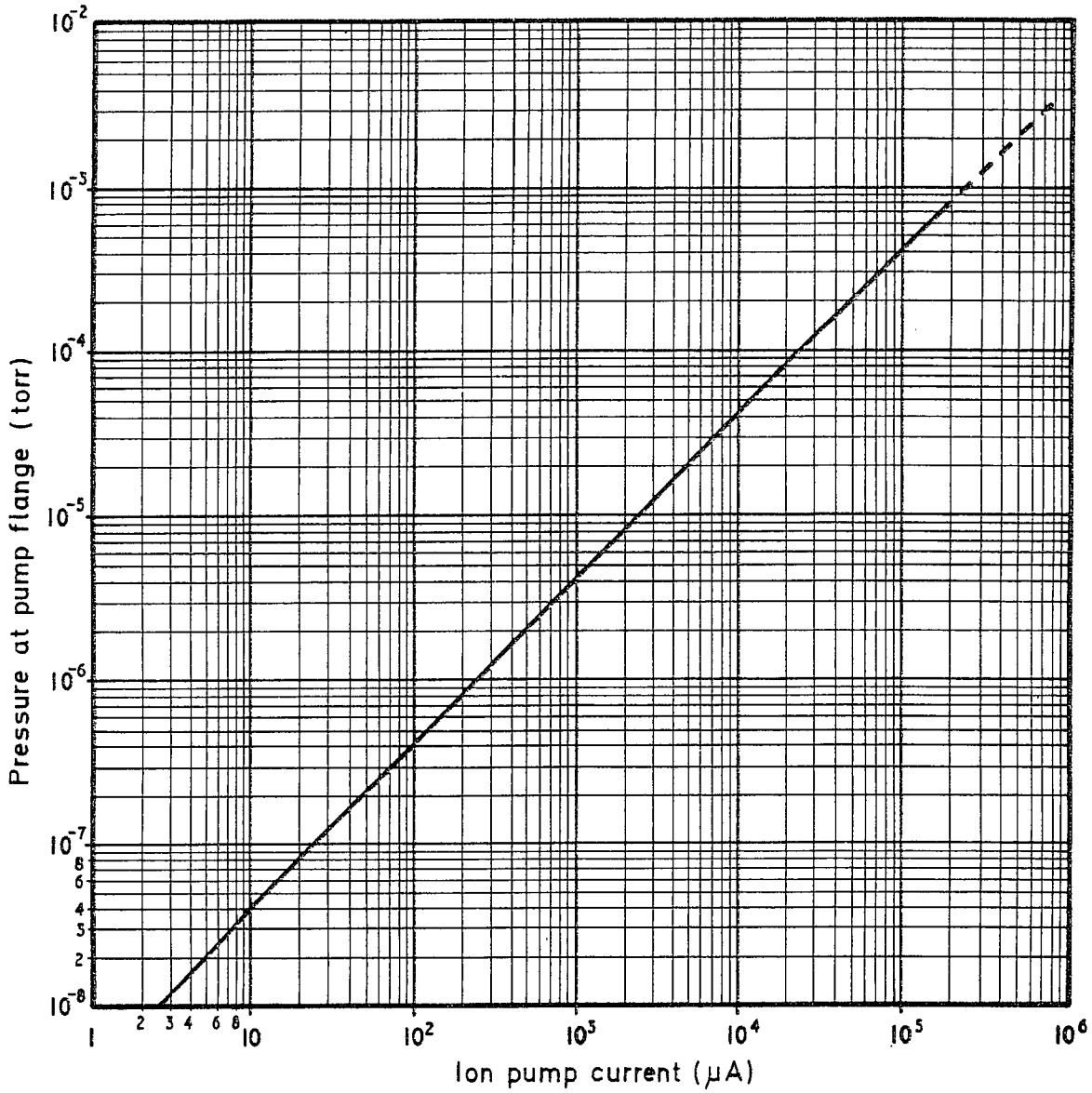


Figure 7: Relationship between current and pressure for ion pump EP1-15

Fault	Possible Cause	Action
Neon lamp extinguished	No mains supply to Pirani gauge	• Check mains connections
		• Check fuse • Check switch.
Meter pointer swings hard over to left (zero)	Element in Pirani gauge head is open-circuited	• Check gauge head for open-circuit between pins 1 and 3 • If open-circuit is confirmed, return Pirani gauge head to the manufacturer for repair and recalibration.
Meter pointer swings hard over to right (f.s.d.)	(1) Element in Pirani gauge head is short-circuited	• Check gauge head for short-circuit between pins 1 and 3 (should be 220 ohms approx.)
	(2) Pirani gauge head is at atmospheric pressure	• If short-circuit is confirmed, return Pirani gauge head to the manufacturer for repair and recalibration.
Meter indicates the wrong pressure	(1) Contamination of Pirani gauge head	• If contaminated, remove element and clean gauge head assembly using trichlorethylene and acetone. Refit element and re-calibrate gauge head.
	(2) Circuit fault in Pirani gauge	• If fault cannot be rectified, return Pirani gauge control unit, together with the gauge head, to the manufacturer for repair.

Figure 8: Fault-finding Guide for Pirani Gauge

Chapter 9: BEAM CONTROL SYSTEM

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1. GENERAL DESCRIPTION

A schematic diagram of the beam control system is shown in Fig. 1. The electrons emitted from the filament in the electron gun are focused into a beam by the electrostatic action of the gun electrodes. The beam is directed through a hole in the anode which leads through the input mode transformer into the accelerator waveguide. In the waveguide the electron beam comes under the influence of the static, axial magnetic field provided by the focus coils surrounding the waveguide over most of its length. The beam is centralised at the input end of the waveguide by two pairs of air-cored coils which are set at right-angles to each other and to the beam to provide two transverse magnetic fields.

During its passage through the accelerator waveguide, the electron beam is acted upon by external magnetic fields including that of the Earth. These produce small unwanted deflections of the beam which vary with Gantry angle. To compensate for these deflections, a second set of centring coils is used. These are located towards the output end of the accelerator waveguide, and produce two transverse magnetic fields that are servo-controlled to maintain the beam at the correct position for entry into the bending magnetic field.

On emerging from the accelerator waveguide, the electron beam passes along a short drift tube and is then transported through the bending magnetic pole-pieces in an evacuated bending chamber. The bending magnet provides a magnetic field transverse to the electron beam. Under its action, the beam is deflected in an arc so that it strikes the centre of the target at right-angles; this produces a symmetrical X-ray field, which by the action of the flattening filter, becomes a flat field in the treatment plane.

The path followed by the beam through the bending chamber depends on the beam energy, the field strength of the bending magnet and the position of entry of the beam into the bending magnet field. The bending magnet field strength is preset in the factory by means of an adjustable shunt across the magnetic poles. The position of entry of the beam into the magnetic field is servo -controlled on two axes 90 degrees apart by the currents in the second set of centring coils. The control signals for these servo-systems are derived by monitoring the output from the accelerator, using the multi-plate IEC ionisation chamber.

The IEC ionisation chamber is mounted in the radiation head immediately below the flattening filter. It consists of three separate ionisation chambers (Dose 1, Dose 2 and Servo) stacked together. The outputs of dose chambers 1 and 2 are used by the dosimetry system as described in Chapter 5: Treatment Control System. The servo chamber is interposed between the dose chambers. It has a segmented "collector" plate that provides symmetry information for servo-controlling field flatness. In the direction transverse to the plane of bending, two segments are used to monitor the two edges of the field. The difference between the two signals derived from these segments is used to control the currents in the 2T centring coils, thereby maintaining transverse field flatness. In the plane of bending, two pairs of monitoring segments are used. The outer pair of segments is situated in an area of the radiation field whose variations in beam energy have the greatest effect and so signals from these are used to control gun emission. The inner pair is in a position where centring errors have most effect and so is used to control the currents in the 2R centring coils. For the purposes of description it is convenient to divide the composite beam control system into its three constituent sub-assemblies, as follows:

- Gun system;
- Focus system;
- Centring system.

2. GUN SYSTEM

2.1 BRIEF DETAILS

Gun emission is determined by the filament heating current which is controlled by means of thyristors in a controlled rectifier bridge in the Gun Filament Power Supply. The filament current is fed to the gun via bifilar windings in the pulse transformer in the Gantry, which isolate the power supply from the 44 kV H.T. pulses from the Modulator. The trigger angle of the thyristors is controlled by a preset 'nominal' voltage on which a servo-correction voltage is superimposed. The servo-correction voltage is derived by monitoring field flatness in the ionisation chamber. When H.T. is switched on, a delay of approximately 6 seconds elapses before emission from the gun begins. This allows time for the magnetron frequency to stabilise. During the delay, the gun filament current is maintained at a standby level. This level is also used when the gun is switched on but H.T. is off.

2.2 SYSTEM DESCRIPTION

Circuit diagrams:

- System diagram : 4513 329 0004, Gp.130, Sht.1
- Interconnection diagram (Gantry) : 4513 326 3000, Gp. 130, Sht.1
- Interconnection diagram (TCC) : 4513 399 7603, Gp.130, Sht.2

Before the Gun Filament Power Supply can be switched on, certain interlock conditions must be fulfilled (see Chapter 3 : Interlocks). Then the Gun On relay RL60-A is energised, either directly if the STANDBY/PREPARATORY key-switch

on the TCC is set to PREPARATORY, or by operation of the GUN ON/OFF switch on the engineer's panel if the key-switch is set to STANDBY. As a result, a.c. mains power is applied to the power supply.

The gun control servo-system is a closed-loop system which maintains the beam energy constant by regulating the gun filament heating current. Constant beam energy ensures a constant trajectory through the bending magnet field and hence field symmetry is maintained.

Control signals for the system originate at two D-shaped segments in the ionisation chamber. These signals consist of small triangular-shaped pulses of current resulting from each X-ray pulse, and are applied to the gantry pre-amplifier. This acts as an impedance converter, and also amplifies and inverts the signals. From here, the signals are routed to the gun servo-error detector circuit PWB76-JJ in the TCC. Since the signals originate from opposite sides of the ionisation chamber, their relative amplitudes are an indication of field symmetry.

On PWB76-JJ, the pulses are each applied to a peak level detector which produces a voltage equivalent to the peak amplitude of the input pulses. The voltage is produced during the period between X-ray pulses, because the ion current in the ionisation chamber does not reach a maximum until well after the X-ray pulse has finished. At the end of the sampling-pulse period the detector circuit is cut-off and held in that state for the duration of the next X-ray pulse, thus avoiding any possibility of interference effects.

The voltages from the two level detectors are compared to provide an error signal of appropriate polarity. This is summed with a fixed signal which is the nominal control voltage required. When the Gun On/Standby changeover relay RLA on PWB76-AA of the TCC is energised for treatment (Gun On), the composite control signal is fed to the thyristor control circuit in the Gun Filament Power Supply. Outputs are also taken direct from the Peak Level Detectors to the Flatness Fault Detector.

A fixed control voltage is applied to the thyristor control circuit in place of the servo-corrected voltage in the following circumstances:

- In between treatments and during the switch-on delay, when a preset 'standby' control signal comes into use automatically, via the Standby contacts of relay RLA on PWB76-LL, to maintain the heater current below emission level. The Gun Standby potentiometer RV11 on PWB76-LL is adjusted to give a standby current of 5 amps.

- If manual control of gun current is required, e.g. during maintenance; an Auto/Manual switch on PWB76-LL may be operated to disconnect the gun servo control signal and substitute a manually adjustable control voltage from a potentiometer on that board.

The a.c. mains supply energises two transformers; one provides a nominal 22 volts a.c. supply for the controlled rectifier bridge, the other provides 20 - 0 - 20 volts a.c. for the thyristor control circuit. In this circuit, the a.c. input is used to synchronise a pulse generator that produces variable width

pulses at twice mains frequency. The duration of each pulse is determined by the control signal from the servo-error detector (or one of the fixed control voltages), together with a feedback signal from the gun current monitor. The pulses are modulated to provide trigger signals for the thyristors in the controlled rectifier bridge. These are turned on for only part of each half cycle, depending on the duration of the control pulses, and so the rectified output after smoothing is variable. The output is fed to the electron gun via the pulse transformer windings where the 44 kV modulator pulses are introduced. Monitoring of gun current is provided by a resistor in the positive side of the output from the controlled rectifier bridge.

For a detailed description of the Servo Detector and Comparator PWB76-JJ, circuit diagram 4513 326 7599, see Chapter 5.

2.3 GUN FILAMENT POWER SUPPLY

- Circuit diagram : 4513 326 3900, Gp.130, Sht.1

The Gun Filament Power Supply, which incorporates the thyristor control circuit PWB39-A, uses a nominal 22 volts a.c. supply from transformer T1. The secondary circuit includes C1, R1 for transient suppression and is protected by a fuse. Controlled rectifier bridge X1 produces a full-wave rectified supply, but the thyristors in the bridge are only able to conduct during part of each half-cycle. The additional diode acoss the output prevents any reverse current from flowing. The rectified output is smoothed by L1 and C5; C4 and R2 suppress any transients in the output. Monitoring resistor R3 provides an output for the engineer's monitor on the TCC and the feedback signal for the thyristor control circuit.

2.4 THYRISTOR CONTROL CIRCUIT : PWB39-A

- Circuit diagram : 4513 326 3964, Gp.130, Sht.1

In the thyristor control circuit, the gun control signal and a feedback signal from the current monitoring resistor are combined in IC4 to produce a corrected control signal. The feedback ensures a constant output from the supply except when error correction is being carried out.

20 - 0 - 20 volts at 50/60Hz from T3 (circuit 4513 326 3900) provides power for the output drivers and, at the same time, provides synchronisation of the thyristor trigger pulses with the a.c. supply to the controlled rectifier bridge. The a.c. input is rectified by diodes D1 to D4 which, together with C8 and C9, provide an unregulated 24 volts d.c. supply for the output driver stages. The 24 volts d.c. is also used by voltage regulators IC5 and IC6 to provide a ±15 volts d.c. supply, balanced about zero voltage, for the control stages. Diodes D5 and D6 apply a full-wave rectified waveform to the base of TR1. This transistor conducts for most of each half-cycle, but is cut off briefly between half-cycles when the voltage at pins 19 and 20 is less than the forward voltage drop across D5, D6. This produces short positive pulses at TR1 collector, which are applied to the inverting input of IC1.

IC1 is a ramp waveform generator. When TR1 is cut off, current is drawn via R4 and D8 into the inverting input of IC1. This causes the output from IC1 to go negative, rapidly charging up C1 until ZD1 conducts, clamping the output at approximately -6 volts. When TR1 conducts again at the end of the pulse, D8 is reverse-biased so preventing current reversal, and C1 then discharges at a constant rate determined by R5. This rate is such that the output from IC1 reaches approximately +6 volts when the next pulse from TR1 is received. Hence, the output from IC1 is a ramp waveform between -6 and +6 volts.

The ramp waveform and the control voltage are summed by R7 and R22 at the input to IC2. The control voltage applies a d.c. bias to the ramp waveform so that it becomes unbalanced about zero voltage. IC2 is a trigger circuit; as long as the summed input is positive, IC2-pin 6 is at +15 volts, and when the summed input is negative, the output is at zero, clamped by D10. The output therefore, is a train of positive pulses whose pulse width is variable according to the control voltage.

The positive pulses from IC2 switch-on a multivibrator circuit made up from two gates in IC3. When the signal at IC3, pin 14 is at zero, the multivibrator is inhibited, but when it is at +15 volts (i.e. when a positive pulse is available from IC2) the multivibrator is enabled and produces a series of trigger pulses for the duration of the positive pulse. The trigger pulses are fed to driver stage TR2, TR3 which is loaded by two transformers T1, T2. The secondaries of the transformers feed directly to the thyristor gates in the controlled rectifier bridge X1.

2.5 GUN DELAY

- Circuit diagram : 4513 390 0054, Gp.130, Sht.1

The 6-seconds gun delay signal is timed from the application of +24 volts via the contacts of HT Hold relay RLD, to the trigger and supply terminals of a timer monostable IC3 on PWB76-LL (pins 1 and 5). The timer action is further subject to the supply of +24 volts to the Gun On relay RLA in the output collector circuit of the timer. This +24 volts is normally available via PWB76-N in the Standby condition or via PWBs 76-P and M in the Preparatory condition. Relay RLA therefore becomes energised after 6 seconds from the application of these two voltages to the timer, its contacts then change-over control of the Thyristor Control Board PWB39-A from the standby level of gun filament current to servo-control. The energisation of relay RLA also produces a similarly delayed treatment start signal that operates via TR2 on Treatment Timer PWB76-M.

3. MAINTENANCE INFORMATION FOR THE GUN SYSTEM

3.1 ELECTRON GUN DETAILS

The electron gun (Fig. 2) is the source of the electrons injected into the accelerator and is pulsed negatively at 44 kV approximately by the same pulses that drive the magnetron. The gun is constructed of two sections: a tubular metal section, and a glass envelope; these are sealed together. The gun is attached to the input end of the accelerator waveguide by a demountable joint

incorporating an O-ring seal. The filament terminals are brought out through the glass envelope, the glass being shaped to provide a long path to prevent tracking over the insulating surface.

The electron source is a directly-heated cathode consisting of a tungsten spiral filament surrounded by a focusing electrode. Due to its finite life, it will be necessary to replace the gun filament from time to time; the procedures for removing the gun and replacing the gun filament are given in the following paragraphs. After refitting the gun to the accelerator, it is necessary to outgas the vacuum system (see Chapter 8 : Vacuum System), and it will also be necessary to set up the gun filament current for optimum X-ray output (see text 7.2.4). After a gun filament replacement, the X-ray field symmetry should be checked and adjusted if necessary (see text 7.3). Note that a slight increase in filament current with life is normally required to maintain optimum X-ray output conditions.

3.2 REMOVAL OF GUN

The following equipment is required:

- 'C' spanner to fit gun coupling ring;
- M4 metric hexagonal socket wrench (Allen key);
- Cylinder of compressed dry nitrogen gas as detailed in Chapter 8;
- Vacuum O-ring No 238 (Viton A elastomer).

Proceed to remove the gun as follows, referring to Fig. 2 as necessary:

(1) Remove the side covers, the upper rear panel and the arm outer (top) cover from the Gantry (see Chapter 2 : Gantry System). The Gantry should now be at the +90 degree position.

(2) Switch off the electrical mains supplies to the equipment, including the Ion Pump Supply, using circuit breakers CB1 and CB2 at Level 4 of the MCC.

(3) Note the orientation of the gun leadouts, and the relative positions of the gun filament leads, so that they can be replaced in the same position later. Disconnect the gun filament leads.

(4) Using the 'C' spanner, slacken the castellated coupling ring by turning it counter-clockwise by one turn approximately.

(5) Open the valve on the nitrogen cylinder and check that the pressure is at least 200 lb/in^2 (14 bar). Do not use the cylinder if the pressure is less than this.

(6) Adjust the reducing valve to give a pressure of 3 to 5 lb/in^2 (0.2 to 0.35 bar). Allow nitrogen to escape for about 30 seconds to dry out any moisture in the nitrogen feedline and expel all air from it.

(7) Remove the dust cap from the vacuum port and hold the adapter at the end of the nitrogen feedline against the vacuum port. Slowly open the vacuum tap on the Linac to allow nitrogen to fill the vacuum system. Continue to hold the adapter in place until a slight back-pressure is felt, indicating that the system is filled with nitrogen at atmospheric pressure.

(8) Close the vacuum tap on the Linac and the valve on the nitrogen cylinder. Replace the dust cap on the vacuum port.

(9) Holding the gun body with one hand, release the coupling ring (use 'C' spanner if necessary). Then carefully withdraw the gun and ring clear of the gun housing and place on a clean surface.

(10) Remove the split-ring segments from the groove in the gun body.

(11) Remove the O-ring from the spigot.

NOTES

1. If the vacuum system has to remain open for more than a few minutes, seal off the opening to prevent the ingress of dust or water vapour.

2. If the replacement of the electron gun will be accomplished quickly and without interruption, a surer method is to bolt the nitrogen gas feedline adapter to the vacuum port and, after the system has been filled, allow the gas to flow continuously from the gun housing on the Linac, but at a reduced gas pressure of 2 lb/in^2 (0.14 bar).

3.3 REPLACEMENT OF GUN

Make ready the replacement gun; preferably this has already been out-gassed and maintained under vacuum until now. Proceed as follows:

(1) Start up the Vacuum Pump Trolley as detailed in Chapter 8, in preparation for its use later.

(2) Place the castellated coupling ring over the gun body.

(3) Ensure that the gun sealing surfaces are free from dust and grease, then carefully position a clean O-ring over the spigot on the gun body.

(4) Carefully slide the gun into its housing in the Linac, taking care that the O-ring does not catch on the housing during insertion. Ensure that the gun leadouts are in their original orientations as noted in text 3.2 (3).

(5) Check that the gun is correctly aligned and not tilted. When fully inserted, the gap between the end of the housing and the groove for the split ring should be less than 2 mm.

(6) Holding the gun body in position on the housing, insert the two split-ring segments in the groove, ensuring that the segments are the correct way round and fully seated in the groove, with the join between segments at top and bottom.

(7) Push the coupling ring over the split ring, ensuring that it fits over the split ring without catching it. Screw up the coupling ring until it is finger-tight. The back edge of the coupling ring should line up approximately with the back edge of the split ring. Check this by viewing through the slots in the coupling ring.

(8) Remove the dust cap from the vacuum port on the Linac and connect the Vacuum Pump Trolley to the vacuum port by means of the flexible pumping line provided, making sure that the O-ring is correctly fitted to the vacuum union.

(9) Set the Pirani gauge to RANGE 1, the 1 torr range, then open tap A on the Vacuum Pump Trolley. Allow about 2 minutes for the flexible line to be evacuated, and check that a pressure of 3 mtorr or less can be attained; (this ensures that no leak exists in the flexible line). Then open the vacuum tap on the Linac, noting the time at which this was done. The Pirani gauge meter indication will rise initially above 1 torr, then start to fall again.

(10) When the Pirani gauge meter indication has fallen below 0.025 torr, set the RANGE switch to RANGE 2, the 25 mtorr range. Tighten up the castellated coupling ring using the 'C' spanner but take care not to overtighten.

(11) Reconnect the gun filament leads to the gun leadouts, as noted in text 3.2 (3).

(12) Check the Pirani gauge meter indication. It should preferably be less than 5 mtorr and must not exceed 10 mtorr. If it is satisfactory, switch-on the Ion Pump Power Supply by means of circuit breaker CB2 at Level 4 of the MCC.

NOTE

For best results, allow the trolley to pump for about 1/2 to 1 hour before switching on the ion pump supply.

(13) Observe the pressure on the vacuum meter over a period of 5 to 10 minutes. If the indicated pressure remains high (e.g. greater than 8 x 10^{-4} torr), switch-off the ion pump and allow the Vacuum Pump Trolley more time to evacuate the Linac before switching on the ion pump again. Repeat this procedure until a slight decrease in meter indication shows that the ion pump is commencing to pump-down the vacuum system.

(14) When the pressure falls to about 1 x 10^{-4} torr, isolate the Vacuum Pump Trolley by closing the vacuum tap on the Linac. If the pressure rises as a result, open the tap again. Repeat this procedure until the tap can be left closed without the pressure rising.

(15) Close down the Vacuum Pump Trolley by setting the RANGE switch to position 1 and switching off the Pirani gauge, closing the two isolation taps A and B, then switching off the rotary pump.

(16) Disconnect the flexible pumping line from the vacuum port on the Linac and replace the dust caps on the vacuum port and flexible pumping line.

(17) Replace the Gantry covers.

(18) Arrange to regenerate the foreline trap.

NOTES

1. After fitting the replacement gun, outgassing effects may be experienced when H.T. is first switched-on. The procedure given in Vol. 1, Chapter 2 for after Linac evacuation should be followed.

2. After fitting a replacement gun, the X-ray field symmetry and flatness should be checked before treatment is recommenced. It should suffice to adjust the 1T and 1R centring supplies by means of RV9 and RV8 on PWB76-LL of the TCC, so as to restore the 2R and 2T centring currents, respectively, to their previously recorded values. For readjustment of the gun servo, use manual control RV7 to obtain the same value of gun filament current as last recorded, then adjust the gun servo for field symmetry as detailed in 7.3.3.

3.4 CHANGING THE GUN FILAMENT

The gun filament is mounted in a sub-assembly (see Fig. 2) comprising a ceramic disc, a carrier consisting of two unequal-size stainless-steel plates and a focusing electrode.

In order to change the gun filament, the gun must first be removed from the Linac (see text 3.2). Then proceed as detailed below, observing the following rules for cleanliness in handling the gun components:

- Wear clean nylon gloves when handling gun components.
- Do not allow any gun component to become contaminated with oil, grease or lint.
- Before use, wipe all tools clean using Ligroin applied with lint-free cloth.

- Carry out gun filament replacement in a clean dry atmosphere and avoid breathing on the components. As components are removed, place them on clean filter paper to avoid contamination.

The following equipment is required:

- 1 pair of clean pointed nose pliers;
- M3 metric hexagonal socket wrench (Allen key);
- M2 metric hexagonal socket wrench (Allen key);
- Screwdriver : 3 mm blade;
- Clean filter paper;
- 1 gun filament.

Proceed as follows, referring to Fig. 2 as necessary:

CAUTION

WHEN SLACKENING OR TIGHTENING SCREWS ON THE GUN, TAKE CARE NOT TO APPLY LEVERAGE TO THE FILAMENT LEADOUT SUPPORTS AS THIS COULD FRACTURE THEIR GLASS SEALS. STAINLESS-STEEL SCREWS ARE USED BECAUSE OF THE VACUUM ENVIRONMENT BUT SUCH SCREWS TEND TO BIND. BECAUSE OF THE CARE TO BE EXERCISED IN SLACKENING THEM, THEY SHOULD ONLY BE SCREWED IN FINGER-TIGHT.

(1) Remove the three M3 screws securing the focusing electrode to one carrier plate then remove the focusing electrode.

NOTE

See 'Caution' above. In view of the difficulty in gripping the focusing electrode by the finger-tips while undoing the screws, two Allen keys may be used instead, one inserted in a screw to prevent rotation of the assembly while the other turns another of the screws. Hold the Allen keys by their shorter ends to lessen the tendency to transmit torque to the whole assembly.

(2) Still observing the above 'Caution', remove the two M2 screws now exposed, which secure the sub-assembly to the leadout supports.

(3) Notice, for later ressembly, the correct orientation of the central and outer filament leads relative to the two dissimilar halves of the carrier plate, which results in the filament spiral being concentric with the aperture in the focusing electrode. Withdraw the

sub-assembly from the gun body and place it on clean filter paper with the filament uppermost.

(4) Using the M2 Allen key, carefully slacken the two grub-screws clamping the filament stems in the carrier plates.

(5) Remove the old filament. Check that the ceramic disc is firmly fastened to the carrier plates.

(6) Gently hold the new filament across the plane of its spiral with pointed-nose pliers, carefully insert the filament stems in the two carrier plate sections. The stems must be pushed fully home so that their ends make contact with the ceramic disc. If a little extra force is necessary, this may be exerted by placing the jaws of the pliers across the bare portion of both stems and applying downward pressure to the tops of the filament-stem sleeves.

(7) Check the filament spiral: it should be flat and undistorted. Confirm that the centre stem of the filament is on the centre-line of the sub-assembly, then (observing the foregoing 'Caution') gently tighten the clamping grub screws just enough to retain the stems. Do not overtighten as this could cause the stem to turn and distort the filament spiral, or it could deform the stem suffiently to jam it in the shaft and so make it difficult to remove next time.

(8) Replace the sub-assembly in the gun body, ensuring that the lead-out supports properly mate, through the ceramic disc, with the counterbore hole in the back of each carrier plate. Carefully secure the sub-assembly in position on the leadout supports using the two M2 screws.

(9) Carefully replace the focusing electrode over the filament and secure it to the carrier plate with the three M3 screws.

3.5 GUN FILAMENT POWER SUPPLY CHECKS

WARNING

BEFORE CARRYING OUT THESE CHECKS, SWITCH OFF THE H.T. CIRCUIT BREAKER CB6 AT LEVEL 4 OF THE MCC.

Check the thyristor control circuit PWB39-A as follows:

(1) Rotate the Gantry to the 0 degrees position and remove the right-hand side cover.

(2) At the TCC, switch-on the gun filament power supply by means of the GUN ON/OFF switch on the engineer's panel.

(3) Using an oscilloscope, check that the waveforms at selected points on the Thyristor Trigger board PWB39-A are typically as shown in Fig. 3.

NOTE

For these conditions, the gun filament current is at the standby level of 5A.

3.6 SETTING UP THE GUN SERVO-SYSTEM

It is convenient to set up the gun servo system at the same time as the two centring servo systems. The procedure is given in text 7.

3.7 SETTING THE GUN STANDBY CURRENT

The gun filament standby current is set to 5A by adjusting RV11 on PWB76-LL whilst observing GUN I on the engineer's monitor. This assumes that the calibration circuit associated with gun current monitoring is correctly set up (see Chapter 5 : Treatment Control System).

4. FOCUS SYSTEM

4.1 GENERAL DESCRIPTION

The focus coils surrounding the accelerator waveguide provide a static axial magnetic field with a focusing action on the electron beam. This field is needed to counteract the defocusing effect of the microwave fields in the accelerator waveguide from which the electrons gain their energy. The focusing field requirements are greatest at the input to the accelerator waveguide and fall-off rapidly as the beam energy increases along the length of the waveguide.

The focus coils are fed from three identical power supplies mounted on the Gantry. There are six coils: four are mounted directly on the water-cooling jacket of the waveguide, and two are fitted around the gun end of the waveguide after it has been inserted into the Gantry arm. Focus Power Supply 1 drives coil 1, Focus P.S.2 drives coil 2 and Focus P.S.3 drives coils 3 to 6 mounted on the waveguide. Control reference voltages for the power supplies are provided by potentiometers on PWB76-LL in the TCC. Basically, these are adjusted to obtain maximum accelerator radiation output consistent with minimum leakage of radiation. Each power supply incorporates an over-current and under-current protection circuit to detect if it is supplying an excessively high or low current. In such a situation, the p.r.f. pulses are inhibited so that the Linac output ceases, and a FOCUS FAULT indication appears on the TCC engineer's panel.

4.2 FOCUS COIL POWER SUPPLIES

- Circuit diagram : 4513 326 3500/1, Gp.130, Sht.1
- Interconnections (Gantry) : 4513 326 3000, Gp.130, Sht.1
- Interconnections (TCC) : 4513 399 7603, Gp.130, Sht.2
- Focus Fault Detection System : 4513 329 0010, Gp.130, Sht.4

The Focus Coil Power Supplies are three thyristor-controlled, current-stabilised supplies located in the gantry. Each supply contains a full-wave controlled rectifier bridge (thyristor stack) and carries two printed-wiring boards, PWB-A and PWB-B. PWB-A comprises a differential amplifier for control purposes and trip circuits for under-current and over-current protection, while PWB-B carries the thyristor trigger circuits for controlling the thyristor stack.

The power for the three focus supplies is provided by the 3-phase a.c. mains, which is fed, via the FOCUS circuit breaker CB5 and the Focus On contactor CON60-B at Level 4 of the MCC, to three transformers T1, T2, T3 in the gantry. Each transformer feeds one power supply and has two secondary windings. One winding provides the power for the controlled rectifier bridge feeding a focus coil set; the other provides a synchronised supply for the thyristor trigger circuit.

The secondary winding supplying power to the controlled rectifier bridge is rated according to the requirements of the coil set that it feeds. The circuit has a fuse and C1, R1 are connected across the winding to suppress transients. The controlled rectifier bridge in the thyristor stack has a 'flywheel' diode connected across its output to prevent any reverse current flow. Transients in the output circuit are suppressed by C5, R3. Current monitoring is provided by R2. The rectified output is smoothed by a choke-capacity filter in each supply.

The control reference voltage for each supply is obtained from RV3, RV4 and RV5 respectively on PWB76-LL in the TCC. The reference voltage is taken as the control input to PWB-A on the Focus power supply where it is compared at IC1 with the voltage from the current monitor R2; (for details see text 4.2.1). The resulting output voltage is applied as the control signal to pin 3 of the Thyristor Trigger board PWB-B.

The thyristor trigger circuit on PWB-B contains a mains-synchronised ramp generator, the output of which operates a switch circuit on reaching a voltage level determined by the control signal. The switch, in turn, operates a free-running oscillator to produce bursts of pulses that are fed via a power driver stage to the controlled rectifier bridge. The level of the control signal governs the switch-on time of the oscillator and hence the triggering angle of the thyristors. Thus, the rectified output from the controlled rectifier bridge is determined by the applied control signal, and is maintained constant by the feedback correction voltage from the current monitor R2; (for a detailed description see following paragraphs).

4.2.1 Focus Supply : PWB-A

The differential amplifier circuit on PWB-A compares a voltage from the appropriate potentiometer on PWB76-LL in the TCC, with the voltage from the current monitor R2 in the power supply output circuit. The two signals are applied to IC1-pins 3 and 2 respectively, and the difference voltage at IC1-pin 6 is fed out as a control voltage via R7 to the thyristor trigger circuit on PWB-B.

Undercurrent protection is provided by IC2 which compares the feed-back signal from current monitor R2 with a preset trip level set by RV1. Normally, the

feedback signal is the larger of the two, and, since it is applied to the inverting input of IC2, the output from IC2-pin 6 will be at -15 volts. If the supply current decreases sufficiently for the feedback voltage to fall below the trip level, the output from IC2 changes to +15 volts. IC3 provides a similar function in respect of excessively high current (over-current), but because the feedback voltage and the trip level set by RV2 are applied to the opposite inputs to those used in IC2, (i.e. the feedback voltage is applied to the non-inverting input), the output from IC3 also changes from -15 to +15 volts when an overcurrent situation arises.

The two 'focus fault' output signals are linked together via R16 and R17 and the resulting signal is fed to the Equipment Fault Drivers and P.R.F. Inhibit circuit on PWB76-BB in the TCC. Because of the link, the 'focus fault' signal is a voltage change from -15 to zero volts. In the absence of a focus fault the signals at PWB76-BB are normally -15 volts. In the event of a focus supply fault, the 'focus fault' signal swings positive (to zero) so that TR2 on PWB76-BB is turned-on and the FOCUS fault lamp is illuminated. Note that the FOCUS lamp may flick-on when H.T. is switched-on due to a transitory under-current condition.

The 'focus fault' signal at PWB76-BB is also coupled via D6 to TR8 which is therefore turned-off, thereby inhibiting the P.R.F. Generator output.

4.2.2 Focus Supply : PWB-B

A 20 volts, 50/60 Hz supply is fed via a fuse FS2 to pins 19 and 20 of PWB-B. The bridge rectifier D1, D2, D5, D6 and capacitors C1, C2 provide an unregulated 24 volts d.c. supply from which a 12 volts stabilised supply is derived by the action of ZD3 and R23 to operate the control circuits.

Diodes D3, D4 provide positive-going, half-sinewave pulses at 100/120 Hz which are used in conjunction with TR1 to generate synchronisation pulses for triggering the ramp waveform generator. During the transition from one pulse to the next, TR1 base voltage is removed and TR1 turns off, allowing C3 to charge via R3 and D7 to a potential determined mainly by ZD1 (i.e. 6.7 volts approx.). When TR1 starts to conduct again, current reversal is prevented by D7 so that C3 remains charged. TR2 forms a constant-current drain, its rate being determined by R5 and R6. Resistor R4 provides some coupling of the half-sinewave pulses to the constant-current drain so that C3 is not discharged linearly but has a cosine waveform superimposed on the ramp waveform. The resulting cosine-discharge ramp waveform repeats at 10 ms intervals (100 Hz frequency). TR3 is an emitter-follower feeding out a cosine-discharge ramp of about 3.5 volts amplitude at R9, R10 junction to the trigger circuit TR4, TR5 (see Fig. 4).

The emitters of TR4, TR5 are held at a voltage determined by the control voltage applied to pin 3 of the board; this determines the point on the ramp at which the trigger circuit operates. At this point TR4 turns-off, TR5 turns-on and C4 charges via R16 to 11.5 volts. TR6 then turns-on, cutting off TR7; this allows TR8 to draw base current via R21 and ZD2. TR8 draws collector current from two sources: the first is through R24 and the primary windings of T1, T2; the second is from C4 via R20 and D8. When C4 is discharged, TR6 turns-off, allowing TR7

to turn on again, thereby cutting off TR8 and allowing C4 to charge again. Thus the circuit acts as an asymmetrical oscillator which can be made to fire at any point in time along the applied ramp waveform by altering the control voltage at the emitters of TR4, TR5.

The output from TR8 to transformers T1 and T2 on PWB 4513 390 0724 is a train of pulses, each pulse of about 30 microseconds duration (C4, R20) and separated in time by 0.5 ms (C4, R16). The duration of the pulse train is variable in steps of 0.5 ms from 0 to 10 ms. The outputs from the secondary windings of T1 and T2 are applied to the gates of the thyristors in the thyristor stack. Capacitors C5, C6 are incorporated to provide decoupling at points where interference pulses might cause spurious triggering of the trigger circuit, while D9 provides protection against reverse voltages for TR8 and the gates of the thyristors.

5. MAINTENANCE INFORMATION FOR THE FOCUS SYSTEM

5.1 FOCUS POWER SUPPLY TESTS

WARNING

TO CARRY OUT THE FOLLOWING TESTS, IT IS NECESSARY FOR ONE PERSON TO BE IN THE RADIATION AREA WHEN THE H.T. SWITCH IS OPERATED. AS THIS CONSTITUTES HAZARDOUS WORKING CONDITIONS THE FOLLOWING PRECAUTIONS MUST BE OBSERVED:

- At Level 4 of the MCC, switch OFF the following circuit breakers,

  - CB6 H.T.;

  - CB7 GUN FIL.

  Attach a notice stating 'DO NOT SWITCH ON' to each of these circuit breakers.

- Close the radiation head diaphragms to their minimum aperture position.

- Switch the P.R.F. selector on the engineer's panel to OFF.

- Ensure that two people are involved during the tests, one in the radiation area and the other to operate the equipment from the TCC.

NOTE

In addition to the above precautions, it is advisable to switch the AFC switch on the engineer's panel to 'MAN'. This will prevent the A.F.C. Servo from driving off-tune when the H.T. switch is operated because there is no R.F. signal for it to sample.

Proceed as follows:

(1) Rotate the Gantry to the 0 degree position and remove the right-hand side cover.

(2) To expose the Focus Power Supply 2 circuits, loosen the two upper screws securing the gantry distribution panel in position and swing the panel down on the lower screws.

(3) Fit the thyristor control board to be tested on an extender card, then switch on H.T. by means of the H.T. switch on the engineer's panel. The Focus contactor CON60-B will be energised, switching on the Focus Power Supplies.

(4) Check the waveforms at selected points on PWB-B in each power supply. They should be typically as shown in Fig. 4.

5.2 SETTING-UP THE FOCUS COIL CURRENTS

The focus coil currents are adjusted during factory tests to provide the maximum useful output from the Linac consistent with a low level of leakage radiation. It is not advisable, therefore, to change appreciably from these current levels. In practice, any resetting of the focus coil currents would normally be necessary only if either a PWB in the power supply had been changed or if any component on the PWBs had been replaced. To set up the currents proceed as follows:

(1) Restore the equipment to normal working, i.e. switch-on the H.T. and GUN FIL circuit breakers at Level 4 of the MCC.

(2) At the TCC select a p.r.f. of 300 p.p.s., then switch on the electron gun.

(3) Switch-on H.T., select DOSE RATE on the engineer's panel and observe the monitor reading.

(4) Maximise the dose rate by adjusting RV3, RV4 and RV5 on PWB76-LL in the TCC (see Fig. 6a). However, see step (5).

(5) On the engineer's monitor, check the three focus power supply currents. These should be within 2% of the values established during the acceptance tests. If they are not, check the leakage radiation level around the Linac before using it for treatment with the new currents set up (see Chapter 12 : X-ray Output).

MAXIMUM DOSE RATE IS NOT NECESSARILY CONSISTENT WITH ACCEPTABLE LEAKAGE LEVELS.

If PWB76-LL has been changed, adjust RV3, RV4 and RV5 in turn whilst monitoring the appropriate current on the engineer's monitor. Set the potentiometers to give the currents established during the acceptance tests.

5.3 SETTING-UP THE OVERCURRENT AND UNDERCURRENT TRIPS

Carry out the following procedure for each power supply in turn:

(1) Check the normal focus power supply current using the engineer's monitor; note the reading.

(2) On PWB76-LL, adjust RV3, RV4 or RV5, as appropriate, in a counter-clockwise direction, until the FOCUS FAULT indicator lights up on the engineer's panel. Note the reading on the engineer's monitor.

(3) Adjust the potentiometer clockwise until the FOCUS FAULT indicator lights up again. Note the reading on the engineer's monitor.

(4) These are the undercurrent and overcurrent trip levels of the supply and should be typically as shown below:

Focus Power Supply	Undercurrent Trip	Normal Current	Overcurrent Trip
1	7 amps	34 amps	38 amps
2	7 amps	25 amps	32 amps
3	7 amps	28 amps	32 amps

(5) If any of the trip levels is out of specification, switch-off H.T., then on PWB-A in the appropriate focus power supply, adjust RV1 or RV2 to change the undercurrent or overcurrent trip level respectively. (see Fig. 6b). Clockwise adjustment of RV1 brings the undercurrent trip level closer to the normal level, whereas clockwise adjustment of RV2 takes the overcurrent trip level further away from the normal level.

(6) Repeat (2) to (5) until the trip levels are correct.

(7) Readjust the potentiometers on PWB76-LL to obtain the normal current reading as noted in step (1).

NOTE

After any adjustments to the potentiometers controlling the focus coil currents, it is advisable to carry out a check of leakage radiation levels around the Linac.

6. BEAM CENTRING SYSTEM

6.1 GENERAL DESCRIPTION

The electron beam in the accelerator waveguide may deviate from the central axis due to small asymmetries in the waveguide structure and the action of external magnetic fields. To compensate for such effects, two sets of air-cored beam centring coils are fitted, one set (1R and 1T) near the gun-end of the other set

(2R and 2T) towards the output end beyond the last focus coil. Each set consists of two pairs of coils producing magnetic fields at right-angles to each other and to the direction of the electron beam. The currents required to control the magnitude and polarity of the magnetic field of each pair of centring coils are provided by the Beam Centring Supplies at Level 2 of the MCC.

The electron beam in the accelerator is affected by the Earth's magnetic field which produces a sideways deviation of the beam. This deviation is reduced to a small amount by the steel shielding provided by the tubular construction of the gantry arm and can be counteracted completely by the centring coils. In use, however, the gantry-mounted accelerator is rotated in the Earth's field, so any correction applied to the centring coils must change with Gantry angle. Although the beam deflection is small, it is sufficient to cause a significant change in the radiation field flatness with rotation. The effect is counteracted by servo-controlling the centring current by means of signals obtained from the edge of the X-ray field from four segments of the ionisation chamber servo plate in the radiation head. The signals are fed to the centring servo-system which automatically adjusts the current in the set of centring coils at the output-end of the waveguide to give a symmetrical X-ray field. The centring coils at the gun-end are not servo-controlled and a simpler form of supply control is incorporated here, the currents in these coils being preset to align the beam centrally in the accelerator at the point of entry (See Fig. 1).

The centring coils are aligned so that they impart specific movements to the beam after it has been bent in the bending field, namely; a radial movement (R) in the plane of bending, and a transverse movement (T) perpendicular to the plane of bending. In the case of the first set of centring coils (1R and 1T) the beam is rotated in the solenoidal focus field, so the R and T relationship is only approximate. In the case of the second set of centring coils (2R and 2T) the correct movement can always be obtained as there is no solenoidal field interaction beyond these centring coils. The 1R, 1T set of coils is used to align the beam from the electron gun in the accelerator and has preset centring currents. The 2R, 2T set is used for servo-control of the beam as described in text 6.3.

The servo-error detection circuits for the 2R and 2T supplies are located in the TCC together with the potentiometers used to provide a fixed control voltage for the 1R and 1T supplies. All four power amplifiers are located at Level 2 of the MCC. Interconnections can be found in the following diagrams:

- Gantry : 4513 326 3000, Gp.130, Sheets 1 and 2
- Monitor and Control Cabinet : 4513 329 6000, Gp.130, Sht.2
- Treatment Control Cabinet : 4513 399 7603, Gp.130, Sht.2
- MCC Level 2 : 4513 329 6100, Gp.130, Sht.1

6.2 1R AND 1T CENTRING SUPPLIES

Fixed control voltages for the 1R and 1T supplies are provided by RV9 and RV8 respectively on PWB76-LL in the TCC. The voltages are routed to PWB61-B (1T)

and PWB61-C (1R), which contain identical power amplifiers providing power for the coils plus a current monitoring output (see text 6.5).

6.3 2R AND 2T CENTRING SUPPLIES

- System diagram : 4513 329 0003, Gp.130, Sht.1

The control voltages for the 2R and 2T centring supplies are derived by monitoring the current signals from two pairs of segments in the ionisation chamber. Each pair of segments produces a pair of current pulses as a result of each pulse of X-radiation generated by the Linac. The relative peak amplitudes of these pulses indicate whether or not the X-ray field is symmetrical.

The pulses from the ionisation chamber are amplified in the gantry pre-amplifier, which also carries out an impedance conversion function. From there they are applied to the servo-error detection circuit on PWB76-FF (2T) or PWB76-HH (2R). In each of these circuits, two peak-level detectors produce voltages equivalent to the peak current levels of the input pulses. The two voltages are then compared to provide an error signal of appropriate polarity. This signal is summed with a fixed signal which is the nominal control voltage required, and the resultant is fed to a power amplifier located on PWB61-D (2T) or PWB61-E (2R). As an alternative to the servo-corrected voltage, a manually-set voltage can be applied to the power amplifier. This is selected by means of the AUTO/MAN switch SW1 on each error-detector board.

The power amplifiers are identical to those used for the 1R and 1T centring supplies (see text 6.5). Each provides stabilised current for the centring coils, and a current monitoring output. The peak-level detectors on the error detector circuits produce a servo-error signal that is fed to the Flatness Fault Detector circuit PWB76-KK in the TCC. If the error signal is excessive, this circuit produces a fault signal which causes treatment termination on Dose Channel 1 (see Chapter 5 : Treatment Control System). The Flatness Fault Detector circuit also produces an error signal for display on the engineer's monitor.

6.4 2R AND 2T SERVO-ERROR DETECTORS AND COMPARATORS : PWBs 76-FF, HH

- Circuit diagrams :

  PWB76-FF (2T Centring) : 4513 326 7597, Gp.130, Sht.1

  PWB76-HH (2R Centring) : 4513 326 7598, Gp.130, Sht.1

The two servo-error detection circuits differ from each other (and from the gun filament servo error detector) only in the values of some of the components affecting the gain of the comparator stage. For the circuit description, refer to Chapter 5.

6.5 POWER AMPLIFIERS

- Circuit diagram : 4513 326 6274, Gp.130, Sht.1

All four pairs of centring coils (1R, 1T, 2R, 2T) are driven by identical power amplifiers located at Level 1 of the MCC. The control voltage from the control potentiometer (1R and 1T) or the servo-error detector (2R and 2T) is applied via a potential divider R1, R2 to operational amplifier IC1. Here it is combined with a feedback signal developed across a 1-ohm resistor R15 in the 0V return from the coils. The output from IC1, pin 6 is applied to the base of TR2, and is also coupled to the base of TR1 by D1. Depending on the polarity and magnitude of the output from IC1, TR1 or TR2 conducts thereby turning on TR3 or TR4 respectively. These two complementary power transistors are connected across the +24 volts lines and so are able to provide forward or reverse current as appropriate for the centring coils. The diode and zener diode combination in the base/emitter circuit of each power transistor prevents it being overdriven by excessive base bias. Resistor R16 feeds a sample of the current for display on the engineer's monitor at the TCC.

7. MAINTENANCE INFORMATION FOR THE BEAM CENTRING SYSTEM

7.1 GENERAL

The currents in the 1R and 1T centring coils are set up in the factory and should not be adjusted, except after gun filament replacement (text 3.3), because leakage radiation may be increased as a result (see Chapter 12 : X-ray Output). Any adjustments necessary to obtain field symmetry should generally be made using the 2R and 2T centring currents. The setting up procedure for the centring and gun servo-systems is detailed in the following text.

7.2 SETTING-UP THE GUN FILAMENT AND BEAM CENTRING SERVO-SYSTEMS

7.2.1 Introduction

The gun filament, 2R centring and 2T centring servo-systems are normally all set-up together because of their interdependence. The adjustments are carried out on the Gun, 2R and 2T Servo Detector and Comparator boards in the TCC, listed below:

- Gun filament : PWB76-JJ
- 2R centring : PWB76-HH
- 2T centring : PWB76-FF

Position the gantry at 0° for all of the following beam centring adjustments and recordings, except where otherwise stated.

7.2.2 Zero Adjustment of the Servo-Systems

Begin the setting-up procedure by adjusting the three servo-detectors and comparators for zero output in the standby state. To do this, connect an oscilloscope or DVM between zero volts (pins 1,22) on the selected board and each of the monitoring points tabled below, in turn, and adjust the appropriate preset control for a null reading.

Gun, 2T and 2R Servo Detector and Comparator boards

PWBs 76-FF, HH, JJ	Adjust for null	Monitor point
Amplifier IC1, Set Zero	RV3	TP1 (pin 6 of IC1)
Amplifier IC2, Set Zero	RV4	TP2 (pin 6 of IC2)
Comparator IC3, Set Zero	RV5	TP4 (pin 6 of IC3)

See Fig. 6c for control layout

7.2.3 Detector Phase Adjustment

Adjust RV2 on PWBs 76-FF, HH and JJ under radiation conditions, in turn, to synchronise the detector sampling pulse with the mid-point of the input signal pulse-width. For this purpose, connect a double-beam oscilloscope to view the sampling pulse at TP3 (collector TR7) and the signal input at coaxial socket A or B of the board.

7.2.4 Setting-Up the Servos for Maximum Dose Rate Output

Initially, the gun filament and centring coil currents are set-up to give the required maximum dose rate at the Linac output. In practice, because of the interaction which occurs between the Gun and 2R servos during setting-up, it is recommended that the gun servo is left undisturbed and kept under automatic control while the 2R servo is set up.

Proceed with the setting-up of the 2R and 2T servos as follows:

(1) Set the 2R and 2T servos to manual operation by means of the AUTO/MAN switch SW1 on boards PWB76-HH and FF (see Fig. 6c).

(2) Set the STANDBY/PREPARATORY key-switch to STANDBY, then on the engineer's panel select a p.r.f. of 50/60 p.p.s. and switch-on H.T.

CAUTION

During initial setting-up, the electron beam may strike the walls of the bending chamber causing overheating in the area. To minimise this, p.r.f. rates must be kept low until maximum dose rate has been achieved.

(3) Adjust RV7 (Manual) on each board to obtain maximum dose rate indication on the engineer's monitor.

NOTE

It is assumed that the AFC Servo-system and the Focus Power Supplies are correctly set up; refer to Chapter 7 : Microwave System (AFC) and text 5 of this Chapter.

(4) Increase the p.r.f. to 300 p.p.s., and make small adjustments to RV7 on each board to maximise the Linac output. Note the 2R and 2T centring currents by displaying 2R-I and 2T-I on the engineer's monitor.

(5) Switch-off H.T. Set the 2R and 2T servos both to AUTO and adjust RV6 (Nominal) on each board to obtain the centring currents noted in (4).

(6) Switch on H.T. and adjust RV1 (Balance) on each board to obtain the same centring currents.

7.3 SETTING-UP X-RAY FIELD SYMMETRY

7.3.1 Test Equipment

The following equipment is required:

- Dose/Dose-Rate meter : Range : 1000 rads/min dose rate; 1000 rads integrated dose; e.g. Pitman 37D.
- Thimble ionisation chamber (for use with dosemeter) : 0.6 cm^3, e.g. Nuclear Enterprises type 2505.
- Polystyrene phantom : 10 x 10 x 10 cm (see Fig. 5).
- Traversing equipment for control of ionisation chamber. : Capable of attachment to the radiation head. Traverse range : ±25 cm with respect the beam central axis.

7.3.2 Preparation

Set up the Linac as follows:

(1) Rotate the radiation head to the 45 degrees position and open the diaphragms fully.

(2) Align the traversing equipment along the G-T axis of the machine.

(3) Ensure that the centre of the ionisation chamber is in the plane of the isocentre.

Because of the interaction between the servo-systems it is essential that they are adjusted in the following order : Gun, 2R, then 2T.

Proceed as follows, referring to Fig. 6c as required:

7.3.3 Dose Symmetry : Gun Servo Adjustment

(1) Maintain the gun servo at AUTO and set the 2R and 2T servos to MAN, using SW1 on each board.

(2) Position the ionisation chamber, fitted in the polystyrene phantom, at the G20 cm point.

(3) At the TCT set up a treatment dose of 100 units. Select a p.r.f. of 300 p.p.s. Set the dose meter to indicate integrated dose.

(4) Start irradiation. When the set dose has been delivered note the indicated dose on the dose meter.

(5) Reposition the ionisation chamber at the T20 cm point. Repeat the 100 unit dose and note the indicated dose on the dose meter at termination.

(6) Adjust 'Balance' potentiometer RV1 on PWB76-JJ (Gun) until the doses measured at the G20 cm and T20 cm points agree to within 1 unit (1%).

(7) Select the GUN-ERROR position on the engineer's monitor and adjust RV6 (Set Nominal) for zero reading.

NOTE

The reading may not be stable due to the servo-action; therefore note the maximum and minimum readings obtained over a period of several seconds and determine the mean error.

(8) On PWB76-JJ (Gun), switch SW1 to MAN and adjust RV7 (Manual) until the same value as the mean-error reading ascertained in (7) above is indicated. (This provides a duplicate of the normal gun servo control setting for future service use if required.)

(9) Repeat steps (1) to (5) and check that the doses measured at G20 cm and T20 cm points are equal to within ±1%. If not, repeat steps (1) to (10) until this requirement is met.

(10) Leave SW1 on PWB76-JJ in the Auto position.

7.3.4 Dose Symmetry : 2R Servo Adjustment

(1) Position the ionisation chamber at the G9 cm and T9 cm points, in turn, and measure the dose delivered at each point for a set dose of 100 units.

(2) Adjust RV7 (Manual) on PWB76-HH (2R) until the doses measured at the G9 cm and T9 cm points are equal to within ±1%.

(3) Select the 2R-ERROR position on the engineer's monitor and adjust RV1 (Balance) on PWB76-HH for a zero reading.

(4) Select the 2R-I position on the engineer's monitor and note the value of 2R current displayed. On PWB76-HH, switch SW1 to AUTO and adjust RV6 (Nominal) to obtain the same mean value of 2R current.

(5) Operate SW1 on PWB76-HH between MAN and AUTO and check that the 2R-I reading (comparing the mean value on AUTO) does not change.

(6) Select the 2R-ERROR position on the engineer's monitor and check that the reading is zero.

(7) Repeat the dose rate measurements for the gun servo at 20 cm points on the G-T axis, as given in 7.3.3 (2) to (5). If necessary, complete the series of adjustments in 7.3.3, and repeat the 2R servo adjustments until the correct field symmetry is obtained. Leave SW1 on PWB76-HH (2R) in the AUTO position.

7.3.5 Dose Symmetry : 2T Servo Adjustment

(1) Position the ionisation chamber at the A20 cm and B20 cm points and measure the dose delivered at each point for a set dose of 100 units.

(2) Adjust RV7 (Manual) on PWB76-FF (2T) until the doses measured at the A20 cm and B20 cm points are equal to within ±1%.

(3) Select the 2T-ERROR position on the engineer's monitor and adjust RV1 (Balance) on PWB76-FF for a zero reading.

(4) Select the 2T-I position on the engineer's monitor and note the value of 2T current displayed. On PWB76-FF, switch SW1 to AUTO and adjust RV6 (Nominal) to obtain the same (mean value of) 2T current.

(5) Operate SW1 on PWB76-FF between MAN and AUTO and check that the 2T-I reading (comparing the mean value on AUTO) does not change.

(6) Select the 2T-ERROR position on the engineer's monitor and check that the reading is zero.

(7) Leave SW1 on PWB76-FF (2T) in the AUTO position.

7.3.6 Dose Symmetry : Overall Check with Gantry Rotation

(1) Recheck field symmetry with all the servos on automatic operation. Make any minor corrections by adjusting RV1 (Balance) on the appropriate board. Reset RV6 (Set Nominal), as necessary, for zero error reading from each servo.

(2) Carry out a similar field symmetry check at three other gantry angles, at 90° intervals from previous position.

7.3.7 Dose Symmetry : Central Beam Axis Check

Position the ionisation chamber on the central beam axis and measure the delivered dose for a set dose of 100 units. This should be within 3% of the dose measured at the 20 cm points on both axes.

7.4 SETTING-UP THE SERVO-ERROR, FLATNESS FAULT, MONITORING AND TRIP CIRCUITS

7.4.1 Preliminary Instructions

Continue to operate in the Standby condition, as detailed under text 7.3 'Setting-up the X-ray Field Symmetry'.

Switch SW1 on Gun servo board PWB76-JJ to AUTO and switch SW1 on 2T, 2R servo boards PWBs 76-FF, HH to MAN.

7.4.2 Flatness Fault Trip Setting : 2R Servo-error

Proceed as follows:

(1) By measurement at TP2 on PWB76-KK, check that there is zero output from the 2R-Error Amplifier IC2 under flat-field conditions (i.e. equal signal inputs at pins 7 and 8 of the board).

(2) Start irradiation and adjust the 2R manual centring control RV7 on PWB76-HH to obtain a field tilt on the G-T axis of 5 ±0.5%. Ascertain the error by measuring the dose at the 9 cm points on the G-T axis, as in clause 7.3.4.

(3) Adjust RV2 on PWB76-KK (see Fig. 9.6d) until the TCC 'FLATNESS FAULT' indication just lights up.

(4) Switch the 2R servo to AUTO to restore field symmetry, then operate the FAULT RESET switch to reset the flatness fault bistable.

(5) Switch the 2R servo to MAN, thus applying the flatness fault condition set-up in step (2) above, and note the time taken for the FLATNESS FAULT indication to reappear. The delay should be approximately 3 seconds and definitely less than 6 seconds.

(6) Adjust the 2R centring Manual control RV7 to reduce the 2R-ERROR reading to zero, then operate the FAULT RESET switch to reset the flatness fault trip circuit.

(7) Switch 2R centring SW1 on PWB76-HH to AUTO.

7.4.3 Flatness Fault Trip Setting : 2T Servo-error

Repeat the test procedure as given in text 7.4.2, but with a field tilt of 5 ±0.5%, measured at 20 cm points on the A-B axis, and using the equivalent 2T centring controls:

2T-Error amplifier output	:	TP1 on PWB76-KK
2T-Error amplifier input	:	Pins 5 and 6 on PWB76-KK
AUTO/MANUAL centring switch	:	SW1 on PWB76-FF
Manual centring control	:	RV7 on PWB76-FF (Fig. 6c)
Flatness fault trip - Set Level	:	RV1 on PWB76-KK (Fig. 6d)

7.4.4 Flatness Fault Trip Setting : Gun Servo-error

Repeat the test procedure as given in text 7.4.2, but with a field tilt of 5 ±0.5%, measured at the 20 cm points on the G-T axis, and using the equivalent Gun-filament servo controls:

Gun-Error amplifier output	:	TP3 on PWB76-KK
Gun-Error amplifier input	:	Pins 11 and 12 on PWB76-KK
AUTO/MANUAL centring switch	:	SW1 on PWB76-JJ
Manual centring control	:	RV7 on PWB76-JJ (Fig. 6c)
Flatness fault trip - Set Level	:	RV3 on PWB76-KK (fig. 6d)

7.4.5 Field Flatness

The foregoing operations have calibrated the 2R, 2T and Gun flatness fault trip circuits for a tilt in the field: it is additionally necessary to calibrate the composite 2R/Gun flatness fault detector IC6 for the presence of a 'hump' or 'depression' in the field.

Proceed as follows:

(1) Confirm by measurement, as before, that equal readings of absorbed dose are obtained at the 9 cm and 20 cm points on the G-T axis.

(2) Check that the two signals at pins 7 and 8 (2R servo error) are equal with respect to 0V; also those at pins 11 and 12 (Gun servo-error).

(3) Adjust RV4 on Flatness Fault Detector board PWB76-KK for zero output at TP4.

(4) Switch-off H.T. Then remove the field-flattening filter from the radiation head. Take a lead disc, 25mm diameter and 2mm thick, and temporarily place it on the centre of the filter.

(5) Switch the Gun, 2R and 2T servos to AUTO and switch the p.r.f. to 300 p.p.s. Switch-on H.T.

(6) Take a plot of the absorbed dose on the G-T axis to verify that a difference of approximately 10% exists between the G9 cm and G20 cm, or the T9 cm and T20 cm, readings. Adjust RV5 (Set Level) on PWB76-KK until the FLATNESS FAULT indicator just lights up.

(7) Switch off H.T. Then remove the modified field-flattening filter, detach the temporary lead disc and refit the normal flattening filter to the radiation head.

(8) Operate the FAULT RESET switch to reset the flatness fault bistable for normal operation.

8. MAINTENANCE INFORMATION FOR THE IONISATION CHAMBER

The plates of the ionisation chamber are made of very thin aluminised Mylar film which is stretched across the path of the radiation beam within an annular housing. The spaces between the plates are filled with ordinary air. For treatment, dose chambers 1 and 2 should be sealed to atmosphere. However, as the plates of sealed chambers may not withstand the pressurisation changes associated with air freight, the ionisation chamber is always supplied unsealed.

Due to their extreme thinness, the plates are easily pierced by sharp objects and rendered useless. A protective cover is therefore fitted over each end of the ionisation chamber. The covers should remain fitted after the ionisation chamber has been installed (see note). For protection when out of the machine, always keep the ionisation chamber in its box.

NOTE

The covers may only remain fitted on x-ray-only machines such as the SL75-5. On machines capable of electron treatment, the covers must be removed.

8.1 TO SEAL DOSE CHAMBERS 1 AND 2

Before fitting new ionisation chamber, it will be necessary to seal the dose chambers.

1. Unpack the new ionisation chamber. Remove its end covers and check that the top and bottom Mylar plates are undamaged.

2. Unpack the ionisation chamber sealing plugs (2 off) being careful not to drop or mislay them - they are VERY small.

3. Prepare a small quantity of Devcon adhesive using the twin-pack provided.

4. Carefully apply a thin coat of Devcon to the underside of each plug cap only, as shown in Fig. 7 (A). Do NOT apply adhesive to the main shaft of the sealing plug or to the ionisation chamber itself.

5. Press the sealing plugs into position, one on each side of the ionisation chamber, as shown in Fig. 7 (B). Rotate each plug until a small, evenly distributed fillet of Devcon is visible around the edge of the plug cap. (Fig. 7 (C)).

6. Replace the ionisation chamber covers using the original M2.5 x 6, 90° countersunk screws. Note that the fixing holes in the covers are polarised to ensure the correct alignment between the circuit references on the cover and the corresponding references on the body of the ionisation chamber. The screws should be properly secured using a Loctite adhesive (e.g. Loctite 222 - Screwlock).

NOTE

At the time of publication of this manual, there is a proposal to supply ionisation chambers having factory-sealed dose chambers filled with dry nitrogen. When this proposal is implemented, the on-site sealing procedure described above will become obsolete.

8.2 TO CHANGE AN IONISATION CHAMBER

1. Remove the diaphragm system as described in Chapter 2. This will expose the ionisation chamber, supported from the collimator on blocks, as shown in Fig. 8.

2. Remove the 2 screws (M4 x 10) fastening the ionisation chamber cableform to the chamber blocks, and unplug all the coax. connectors from around the chamber.

3. Remove 2 screws (M5 x 10) to release the ionisation chamber complete with its chamber supports. Transfer these supports to the new ionisation chamber.

NOTE

The new ionisation chamber must be sealed as described above under "TO SEAL DOSE CHAMBERS 1 AND 2".

4. Replacement is a reversal of the removal procedure.

* * * * *

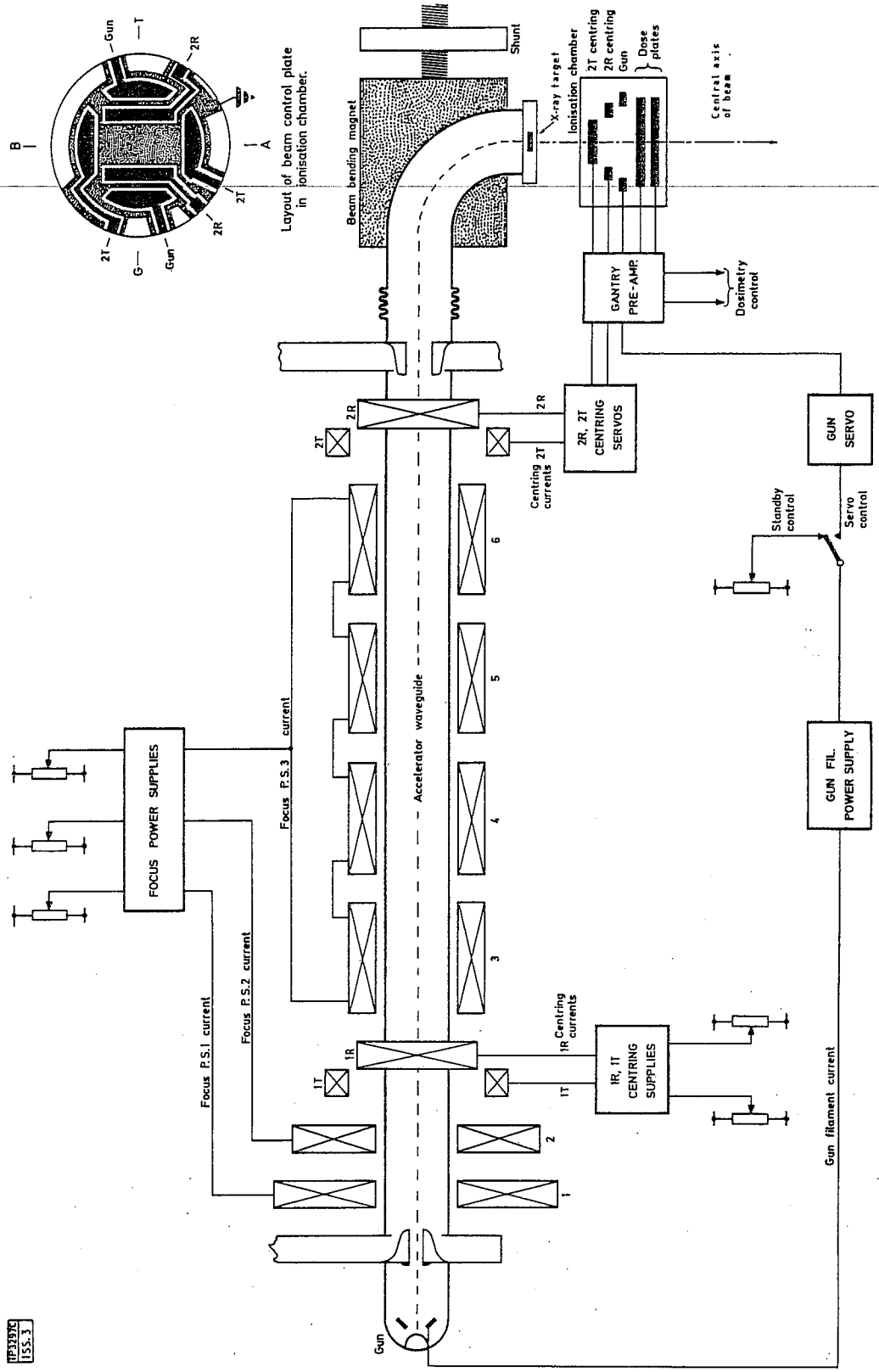


Figure 1: Beam Control System, schematic diagram

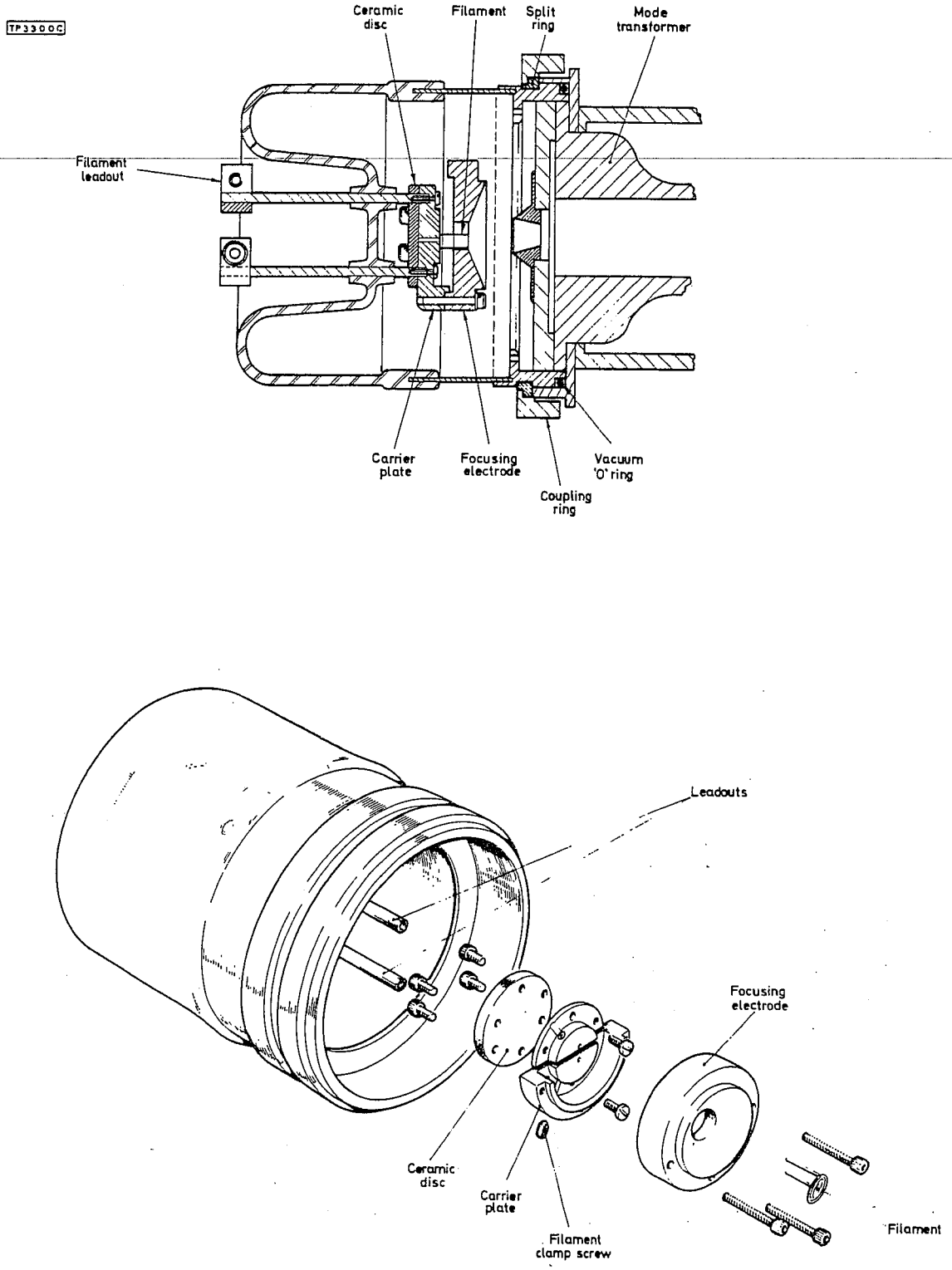
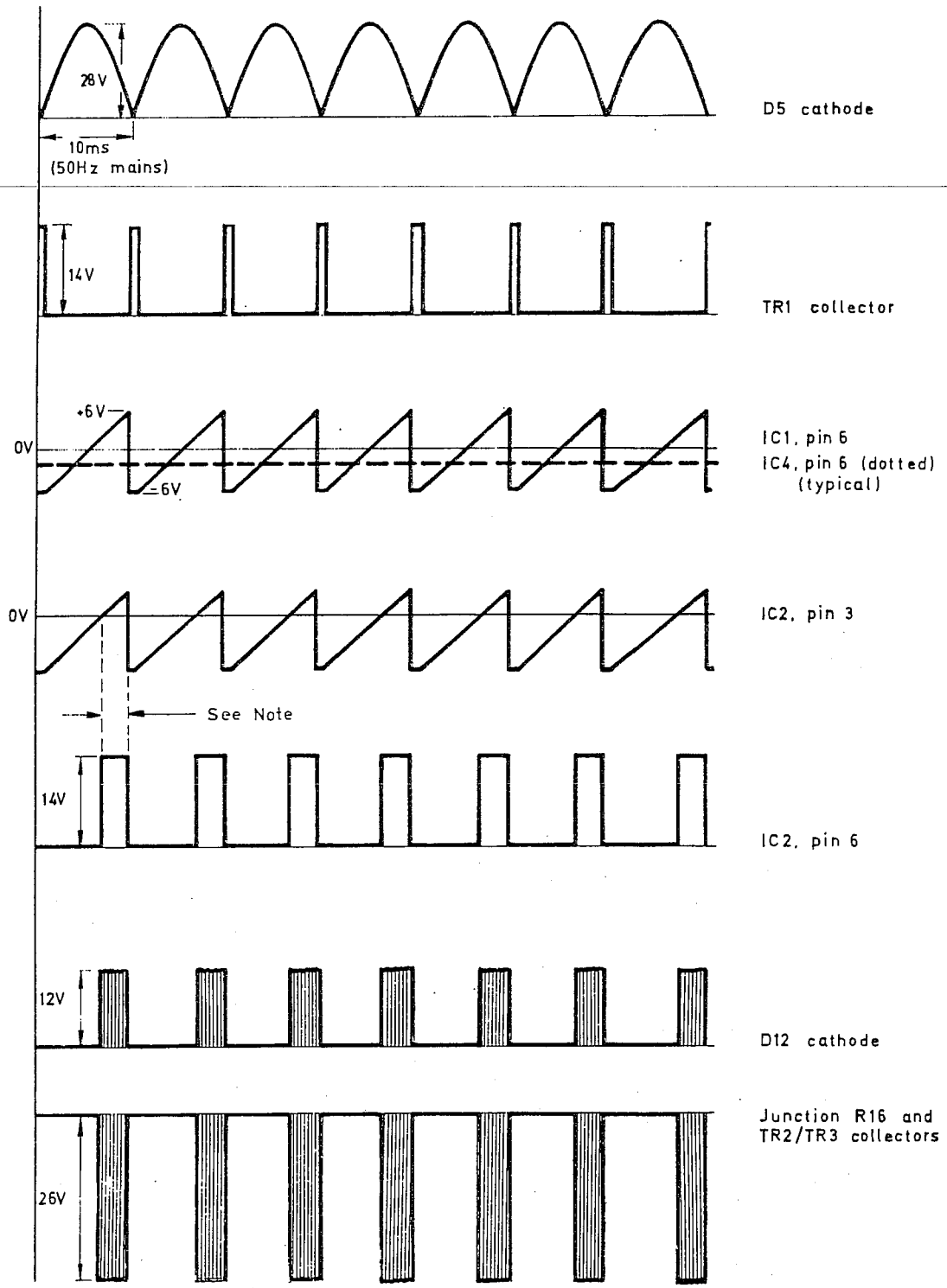


Figure 2: Electron Gun



Note: Pulse width is determined by amount of voltage from IC4, pin 6

Figure 3: Gun Filament Power Supply, waveforms on PWB39-A

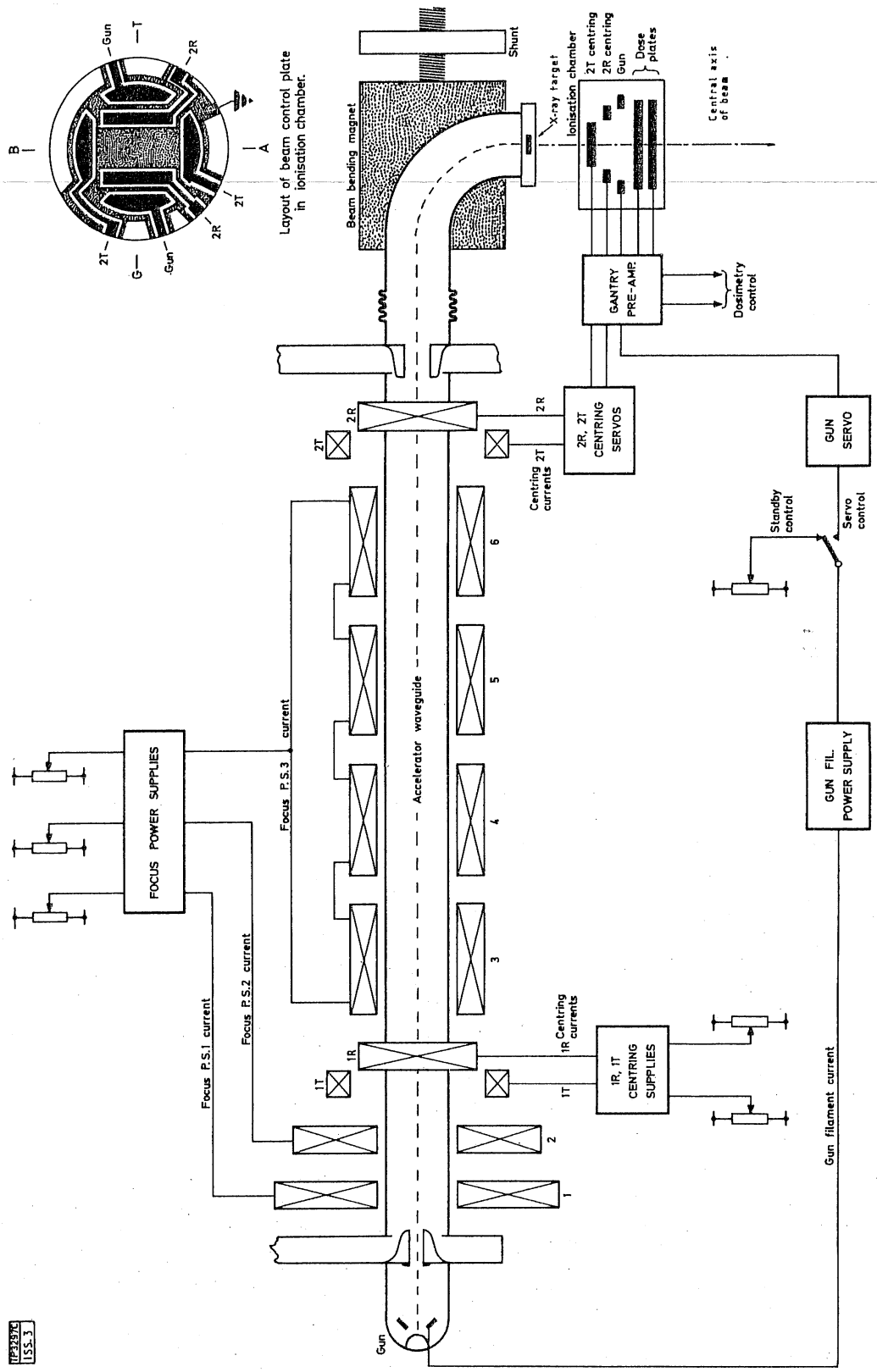


Figure 1: Beam Control System, schematic diagram

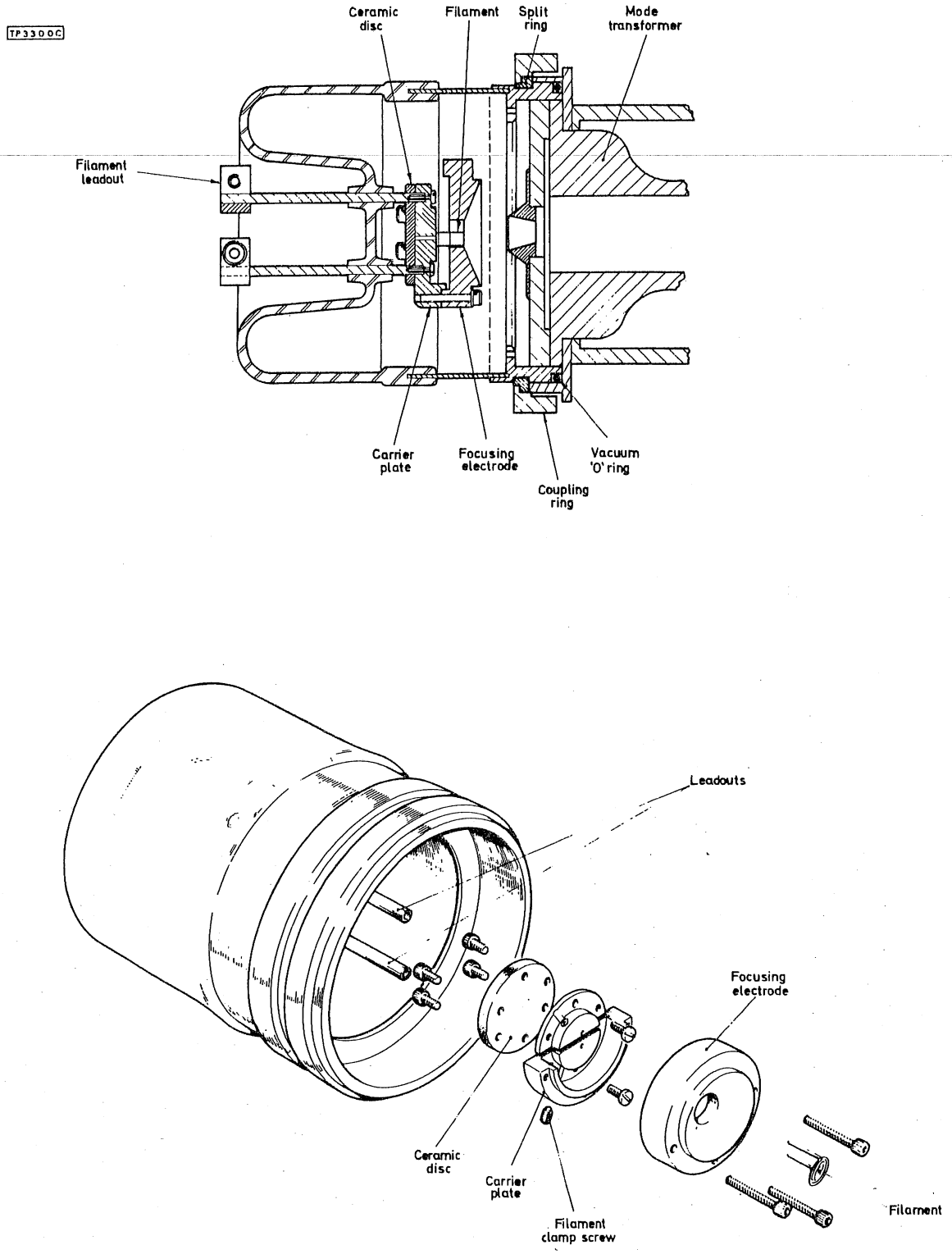
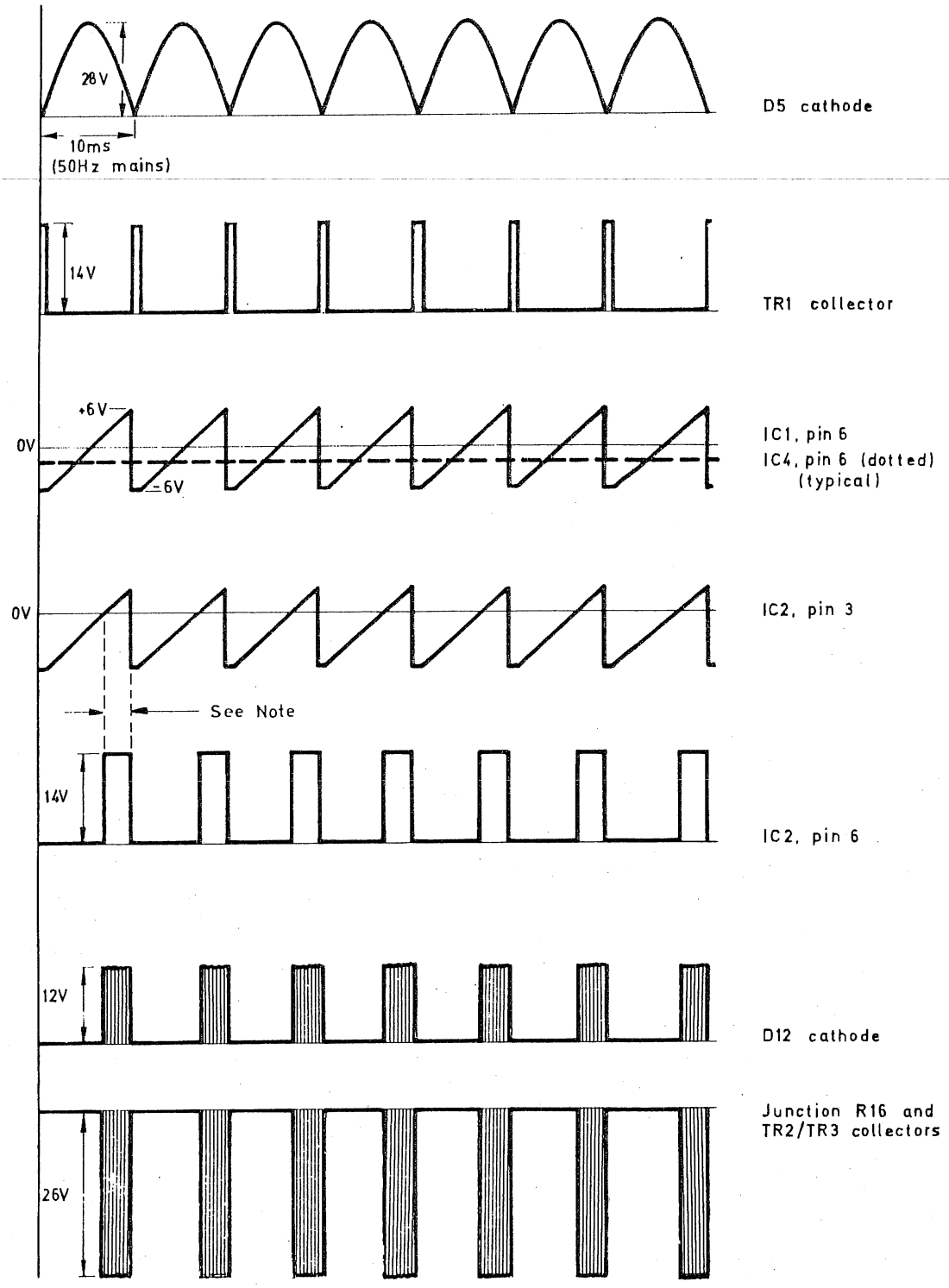


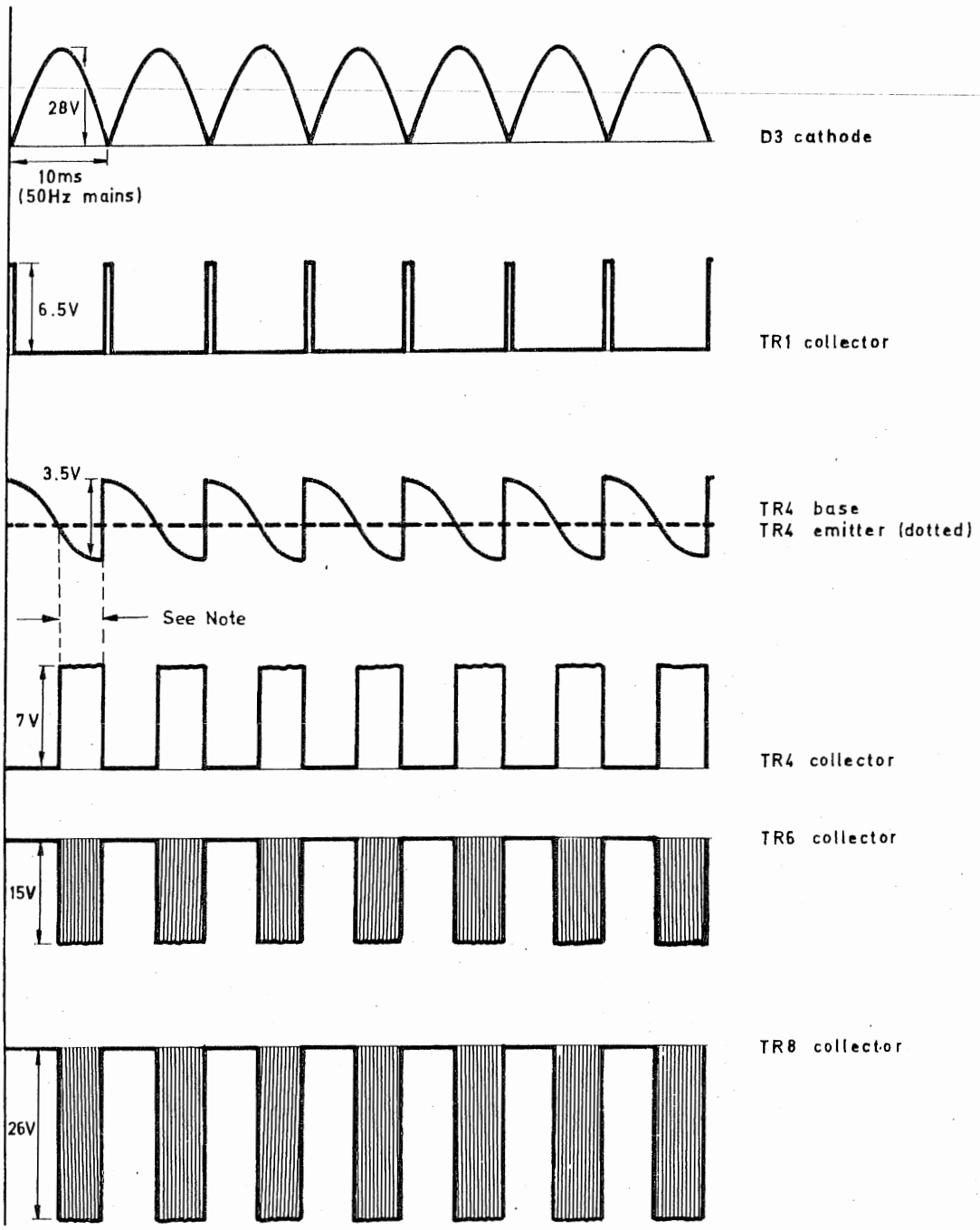
Figure 2: Electron Gun



Note: Pulse width is determined by amount of voltage from IC4, pin 6

Figure 3: Gun Filament Power Supply, waveforms on PWB39-A

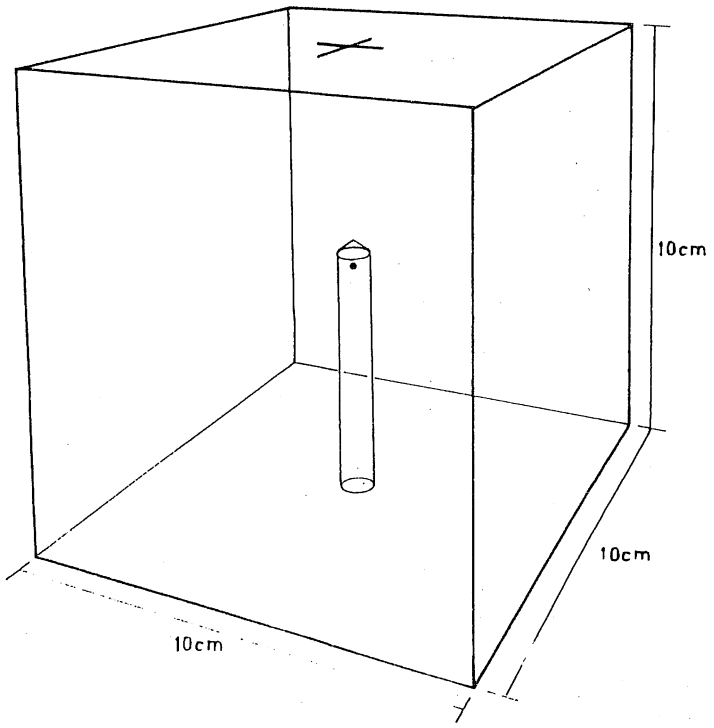
TP3304A
ISS.2



Note: Pulse width is determined by amount of control voltage on TR4 emitter

Figure 4: Focus Power Supply, waveforms on PWB-B

TP3307A



Hole: Diam: To suit thimble ionisation chamber
Depth: Sufficient to position centre of ion chamber 5cm from upper surface

Figure 5: Polystyrene Phantom

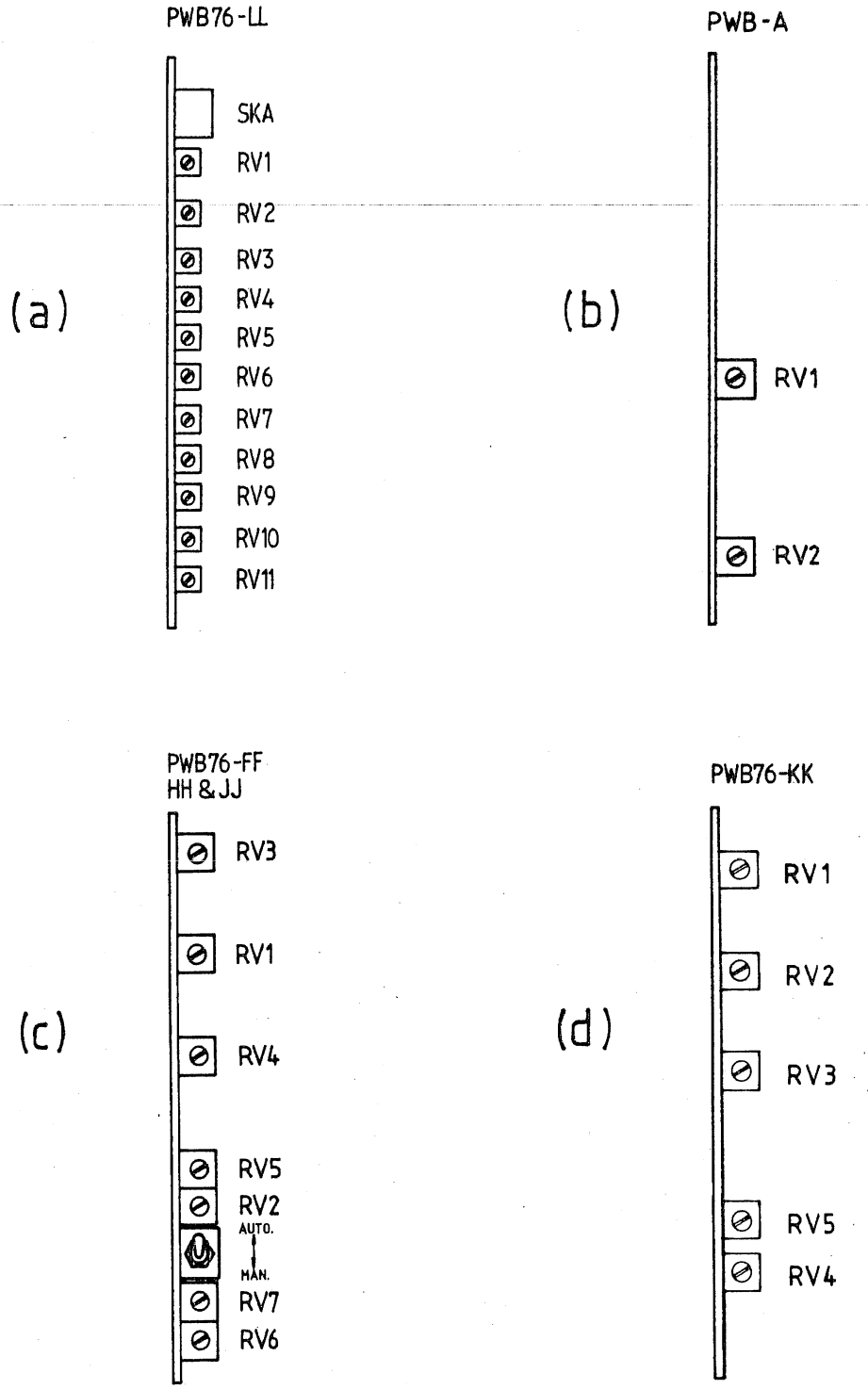


Figure 6: Layout of Control Potentiometers on the Control Boards

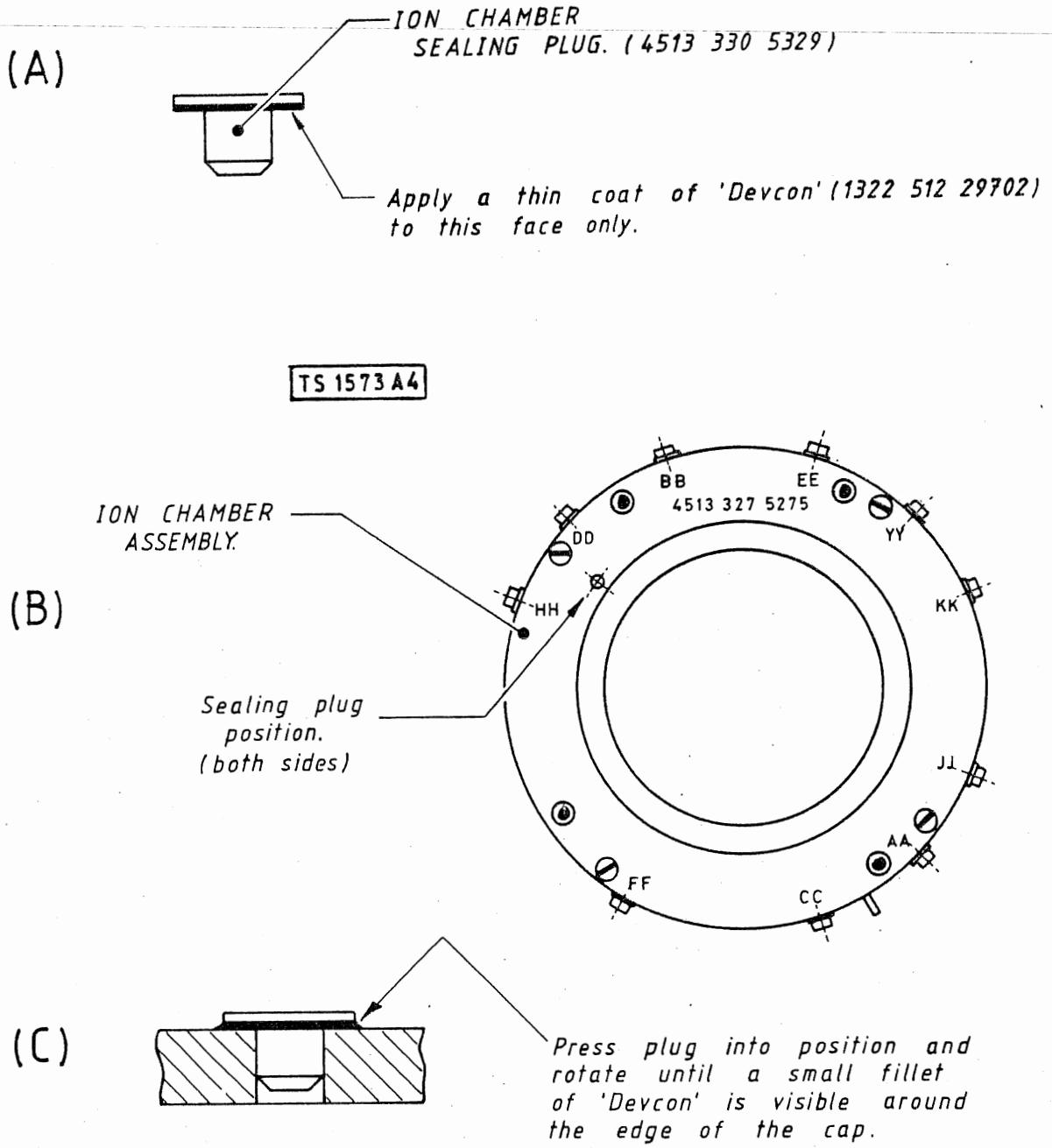
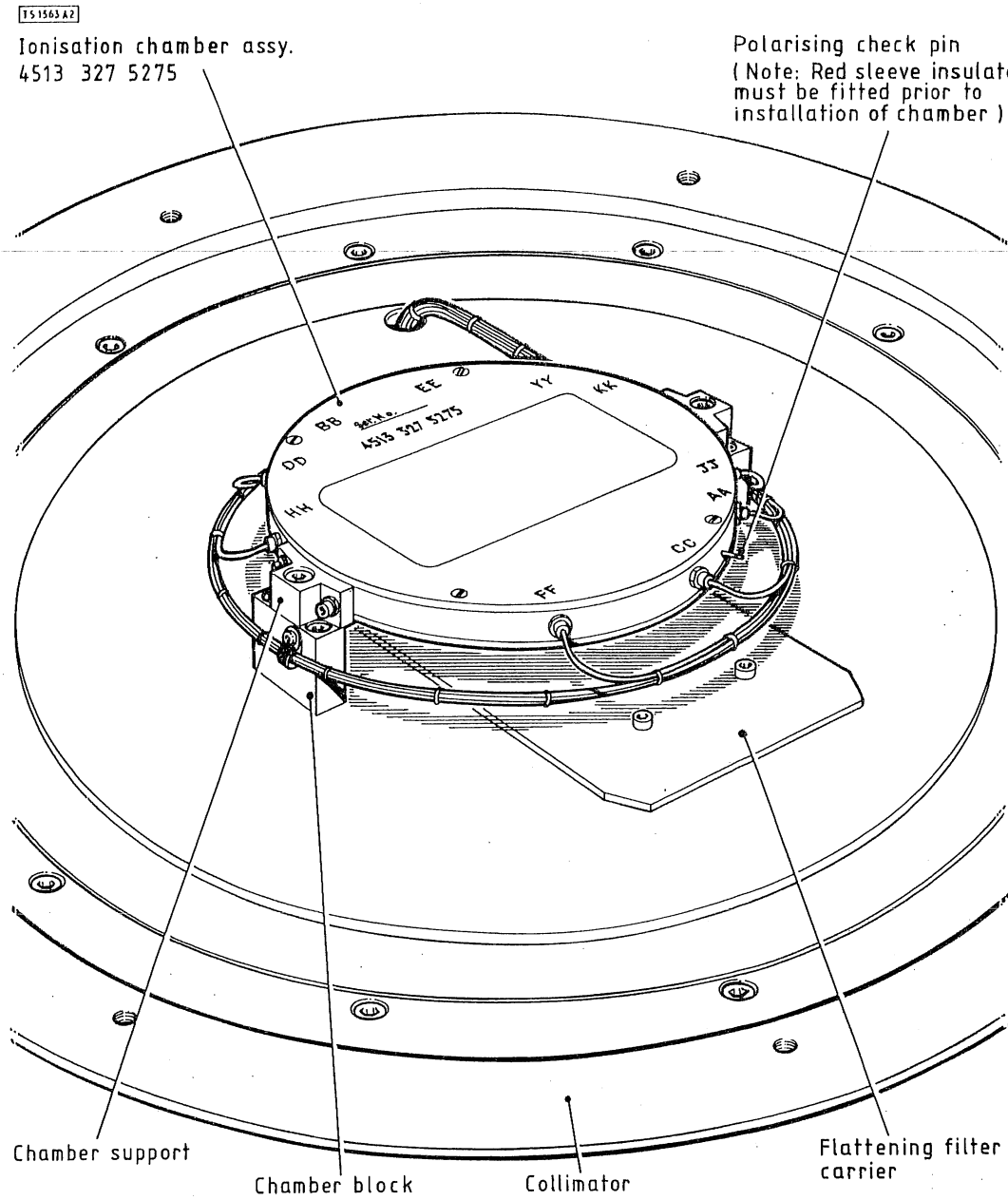


Figure 7: Ionisation Chamber Sealing



VIEW ON FRONT OF IONISATION CHAMBER SHOWING COVER LABEL

WARNING

REMOVE ION CHAMBER COVERS PRIOR TO INSTALLATION IN ORDER TO IMPLEMENT SEALING PROCEDURE 4513 327 5275 GRP165. REPLACE COVERS FOR DEDICATED X-RAY MACHINES ONLY (NOT ELECTRON THERAPY MACHINES)

Figure 8: Ionisation Chamber Mounting

Chapter 10: MOVEMENTS CONTROL SYSTEM

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1. GENERAL INFORMATION

The movements control system enables the gantry and its radiation head to be adjusted readily to the correct positions for the application of a treatment dose. The principal units involved are the Movements Controller, and the motor control PWBs in the MCC. Two different types of motor-control systems are employed: one, for a Large H.P. Motor, is used to drive the Gantry Motor; the other, for Small H.P. motors is used to provide the movements for the radiation head i.e. to rotate the radiation head (one motor) and to vary the aperture of the inner and outer diaphragms (two motors).

Each motor control system produces controlled 100-120 Hz pulses of drive power for controlling the speed and direction of the associated motors. For the Large H.P. Motor, phase-controlled unidirectional a.c. power pulses are applied to separate field windings of the motor via a thyristor power stage. For the Small H.P. Motor, positive or negative-going pulses of controlled pulse-width at 100-120 Hz are applied to the motor.

2. MOVEMENTS CONTROLLER (Fig. 1)

Circuit diagrams:

- Movements interlocks and control system : 4513 329 0010, Gp.130, Shts. 3 & 1
- Pendant type Movements Controller : 4513 399 0860, Gp.130, Sht. 1

2.1 MOVEMENTS CONTROLS

The Movements Controller carries controls on its front panel for the various movements of the Linac. These controls consist of thumbwheel switches which are used to provide control signals to the motor-control boards for the following movements:

- Gantry rotation;
- Diaphragm system rotation;
- Field size set by X diaphragms;
- Field size set by Y diaphragms;
- Patient Support System Table lift, for initial table-height control.

Each thumbwheel is biased towards its central 'off' position, and the direction in which it is moved determines the direction of movement of the associated motor system, while the amount of travel of the thumbwheel is directly proportional to the speed of this movement. A digital readout of position for the various movements is provided on the VDU in the treatment room (24-inch TV monitor).

To guard against inadvertent operation of the thumbwheel controls, each motor-control system is operative only when the 'movements enable' switch is depressed

and the 'movements' interlocks are all made. Constraints on the amount of movement are provided in each case by mechanically-actuated limit switches and also by a touchguard on the radiation head, and on the beam absorber if fitted. If the Gantry over-travels and actuates the appropriate Limit 1 switch, the motor-control system is rendered inoperative for that particular direction of travel. If, however, the touchguard meets an obstacle, the motor-control system is rendered inoperative for both directions of travel; this condition applies also if the Limit 2 switch is actuated.

In addition to the thumbwheel controls, the Movements Controller carries illuminated push-button switches as follows:

TOUCHGUARD	:	Press and hold in to override the touchguard switches while operating the appropriate thumbwheel.
FIELD	:	Press to switch-on the field-defining lamp on the radiation head. Press again to switch-off this lamp.
DIM LIGHT	:	Press to reduce the level of room lighting. Press again to restore the room lighting fully.
DISTANCE METER	:	Press to switch-on the optical distance meter. Press again to switch-off this meter.
STOP MOTORS	:	Press to stop all motors in the movements system instantly. Press again to unlatch the switch.
STOP MOTOR RESET	:	Press to restore motor control to the movements system, then release.
NEXT PAGE	:	Press to change the page of the Vericord treatment room display, where used.
AUTO SET-UP	:	Functional only when the optional Auto Set-up system is incorporated.
BEAM ABSORBER	:	Only if the optional beam absorber is fitted. Press to extend the beam absorber; press again to retract it.

Before any movement can be made using the thumbwheel controls, the 'movements enable' safety switch must be operated; this is done by pressing the spring loaded movable bar at the back of the pendant-type Movements Controller. As a result, +24 volts is routed through to the motor-control boards to enable the movements.

2.2 MOVEMENTS 'SYSTEMS READY' CONDITION

Power for the movements system is supplied when the Supplies On contactor CON60-A in the MCC is energised. This connects the 240 volts (nominal) a.c. supply via the MOVEMENTS circuit breaker CB10 and the contacts of the Stop Motors contacts CON60-D to transformer T1 on Level 2 of the MCC., and to energise relay RL62-J. Transformer T1 is the source of 100/120 Hz mains

synchronisation trigger signals for the Large H.P. Motor Control Board; its two bridge rectified outputs provide +24 volts d.c. supplies for the Small H.P. Motor Control Boards on Level 2 of the MCC and for the Patient Support System. One +24 volts output also provides the Systems Ready interlock supply. Provided that the touchguard interlocks chain is complete (see Chap. 3 for details), Touchguard relay RL62-K is energised and the warning lamp in the Touchguard push-button is extinguished; +24 volts is then fed as a Movement Systems Ready signal to the TCC (Treatment Start circuit and PWB76-P) and the SYSTEMS READY indicator on the Movement Controller is illuminated to signify this condition.

2.3 DIGITAL READOUT OF POSITION

Digital readout for each of the four movements is provided on the TCT and treatment room VDU by the following method. Positional analogue data for the movement is obtained from a precision potentiometer coupled to the associated motor; this data is fed to the Monitor and Data Readout Panel on Level 1 of the MCC for calibration. The position-signal from the associated calibration amplifier is then taken to the TCC where the Gantry Angle and Head Angle signals (±4.5 volts = ±180°) are recalibrated for 0-360° (0-5 volts) on PWBs 76-D and AB respectively. Together with the Inner Diaphragms and Outer Diaphragms position signals, they are then subjected to analogue-to-digital conversion on PWB76-D, before further processing for display on the TCT and Treatment Room VDU.

3. MOTOR CONTROL

3.1 ARRANGEMENTS FOR MOTOR CONTROL

The speed and direction of rotation of motor movement results from a positive or negative control signal which is fed from the appropriate thumbwheel control on the Movements Controller to the associated motor-control board in the MCC. The thumbwheel control is a lever-operated potentiometer connected between ±15 volts, and is spring-biased to the central 'off' position. Movement of the thumbwheel control from the central 'off' position, in either direction, increases the control signal to the motor-control board from zero, and also closes the 'movements' switch linked to the control. If the 'movements enable' switch on the Movements Controller is also depressed, the movement is enabled.

The Gantry Drive motor for rotating the gantry is a large h.p. motor of the split-field type controlled by a pair of PWBs on Level 2 of the MCC. The pair of PWBs consist of a Large H.P. Logic Motor Control Board PWB62-A and a Thyristor Power Control board PWB62-B. On applying a positive or negative voltage control signal to the motor control board under 'systems ready' conditions, rotation of the Gantry Drive motor is produced by the thyristor drive to the appropriate half of the split-field motor winding.

Small h.p. motors of the 24 volts d.c. permanent magnet type are used for the following movements:

- Diaphragm system rotation (head angle);
- Inner diaphragm movement (setting Y field size);

- Outer diaphragms movement (setting X field size).

The ±24 volts d.c. power supplies for the three motors are routed via the contacts of RL62-J which are closed provided that the Stop Motors push-button switch is not actuated.

Each small h.p. motor is controlled from a Motor Control board on Level 2 of the MCC; the board adjusts the speed and direction of rotation of the associated motor in accordance with control signals from the Movements Controller. The control signal originates as a d.c. voltage from the appropriate thumbwheel control, and this is applied to the corresponding Motor Control Board (PWB62-C, D or E) where it is combined with a speed-sensitive correction voltage provided by the back e.m.f. of the motor.

3.2 MOVEMENTS LIMITS

Constraints are imposed on all movements by mechanically-operated limit switches. If a movement overtravels and actuates a Limit 1 switch, the motor is inoperative for further movement in that particular direction. If a touchguard meets an obstacle, the Gantry Drive Motor is inoperative for both directions of travel; this applies also if a Limit 2 switch is actuated. The touchguard, however, can be overridden by use of the TOUCHGUARD push-button on the Movements Controller, thereby enabling the touchguard to be moved clear of the obstacle; the Gantry Limit 2 switch cannot be overriden.

When a Gantry Limit 2 switch is operated, all movement control of the Gantry Drive Motor is inhibited. The reason for overriding the Limit 1 switch must be investigated before proceeding further. To regain control, it is necessary to switch-off all power supplies to the Gantry and then rotate the motor manually until the Limit 2 switch is no longer actuated. The Gantry can then be rotated under power in the same direction until its actuator is clear of the Limit 1 switch, thereby restoring normal movement control.

3.3 'STOP MOTORS' EMERGENCY BUTTON

- Circuit diagram : 4513 329 0010, Gp.130, Sht.3

If the STOP MOTORS push-button on the Movements Controller is pressed, the +24 volts supply via the Gantry Limit 2 switches and the Patient Support System interlocks (where applicable) is broken and the Stop Motors relay RL60-F is de-energised. As a result, the Stop Motors contactor CON60-D is de-energised and switches-off the mains supply from the Movements circuit breaker CB10 to Level 4 of the MCC, thereby immobilising all motors on the Gantry and Patient Support System. In the process:

- T1 and RL62-J are de-energised, thus switching off and disconnecting the ±24 volts d.c. power supplies to the Small H.P. Motor Control Boards, the Patient Support System and the +24 volts for the 'Systems Ready' interlocks. The a.c. mains synchronisation voltage for the Large H.P. Motor Control Board is also thereby switched off.

- The Touchguard relay RL62-K is de-energised. As a result, the logic control circuit of the gantry drive motor is inhibited and the 'Systems Ready' interlock circuit is broken (in addition to its d.c. supply being disconnected by RL62-J).

- Power is removed from the 'movements enable' switch of the Movements Controller, de-energising all Motor Relays (RL62-B, C, D and E, including RL89-B, E in the Patient Support System) so that all movements are inoperative. In addition, relay RL85-A, which acts as an extension of the movements enable switch S-J/K, is de-energised and so isolates the Table Lift thumbwheel control from the Patient Support System, as normal, until the switch is pressed. The other set of RLA contacts shown in the circuit diagram are part of the optional Auto Set-Up system.

- De-energisation of the gantry motor relay RL62-B consequently breaks the +24 volts supply to the clutch of the gantry drive motor. It also causes RL62-A to be de-energised, thus disconnecting the a.c. mains supply to the Thyristor Power Control board of the gantry drive motor.

4. CONTROL OF GANTRY ROTATION

4.1 CIRCUIT DIAGRAMS

- Movements control system : 4513 329 0010, Gp.130-3
- Motor Control Board (Large H.P. Motors) : 4513 390 0244, Gp.130-1
- Thyristor Power Control PWB62-B : 4513 390 0354, Gp.130-1

4.2 RELAYS

The control system for Gantry rotation utilises four relays on Level 2 of the MCC and a solenoid-operated clutch that couples the Gantry Drive motor to its gearbox. These components are energised under the following control conditions:

- RL62-A (Movements relay) : energised when Stop Motors relay RL60-F (and consequently contactor CON60-D) and Motor Relay RL62-B are energised.

- RL62-B (Motor relay) : energised via the Movements Controller 'movements enable' switch for manual control or via the TCC for Arc Therapy, when certain safety conditions have been met.

- RL62-K (Head Touchguard relay) : energised via the normally closed contacts of:

  - Stop Motors push-button;

- Gantry Limit 2 switches;
- P.S.S. interlocks (where applicable);
- Shadow Tray interlocks;
- Radiation head and beam absorber touchguard switches.

4.3 GANTRY MOTOR CLUTCH

Provided that the safety interlocks are complete so that Touchguard relay RL62-K is energised (see text 2.2), operation of the Movements Controller 'movements enable' switch energises the gantry Motor Relay RL62-B whose contacts (21, 24) then connect +24 volts to energise and engage the clutch in readiness for gantry rotation when the thumbwheel control is operated.

4.4 SPEED AND DIRECTION CONTROL

The control signal which determines the speed and direction of rotation of the Gantry Drive motor originates as a d.c. voltage from the wiper of the thumbwheel control TWS-D on the Movements Controller; (+ve for c.w. rotation, -ve for c.c.w. rotation). This voltage is fed out via a buffer amplifier to the Logic Motor Control board PWB62-A (pin 6). The function of this board is to produce bursts of trigger pulses for the Thyristor Power Control board PWB62-B which drives the motor; the power from the thyristor board is fed directly to the appropriate half of the split-field windings of the motor.

A tacho-generator driven by the motor generates a d.c. voltage proportional to the motor speed, and this signal is fed to PWB62-B (pin H) where it is combined in opposite polarity with the control signal to provide a speed-correction signal.

4.5 MOTOR CURRENT LIMITATION

In normal operation the motor-starting current is kept within acceptable limits by resistor R4 in series with the armature and field current circuit. Under surge or stalled conditions, additional protection for the motor and driver stages is provided by an active current-limiting circuit operating from the series voltage drop across R4. This voltage, which is proportional to motor current, is sampled on the Large H.P. Motor Control board PWB62-A at pins B and 2, with the result that an increase in motor current, beyond a predetermined value, reduces the conduction angle of the thyristors on PWB62-B so that the motor current is limited.

4.6 LARGE H.P. MOTOR CONTROL BOARD : PWB62-A

- Circuit diagram : 4513 390 0244, Gp.130.1

4.6.1 General Description

The function of this Logic Motor Control board is to produce bursts of trigger pulses for the associated Thyristor Power Control board which drives the motor. The bursts of pulses are fed out from one of two outputs, depending on the polarity of the input control voltage; the duration of each burst depends on the amplitude of the voltage while the frequency of the burst is 5-10 kHz with repetition rate of 100-120 Hz. The board also carries a number of control and gating circuits, not all of which are used in this application.

The inputs to the board gating circuits are derived as follows:

Pin 14	NOT SAFE 1	:	Connected to zero volts when 'movements enable' switch and the gantry movement control on the Controller are operated and relay RL62-K (Touchguard) is energised.
Pin R	NOT SAFE 2	:	Connected to zero volts when 'movements enable' switch and the gantry movement control on the Controller are operated; also to zero volts when arc therapy is initiated.
Pin 12	NOT PI	:	Connected to zero volts when arc therapy is initiated.
Pin N	NOT ACC	:	Connected to zero volts when arc therapy is initiated.
Pin M	NOT EXT	:	Connected when an external control is used.
Pin 13	NOT CCW	:	Connected to zero volts unless the associated Limit 1 switch is operated, it then goes open circuit.
Pin P	NOT CW	:	Connected to zero volts unless the associated Limit 1 switch is operated, it then goes open circuit.
Pin 11	NOT STOP	:	Not connected in this application.

The board carries the following potentiometer controls:

RV1 : Set gain (summing amplifier)

RV2 : Set current limit

RV3 : Zero offset (summing amplifier)

For manual operation the control voltage is applied to pin 6 of the board from where it is fed, via steering diodes D1 or D2 and TR1 or TR2, to a summing

amplifier IC1. The switching-on of TR1 and TR2 to enable the control signal is controlled by two similar diode logic AND gates, D14-18 and D21-25. When the 'movements enable' switch (S-J,K and L,M) is pressed and the movement control lever (TWS-D) is operated, a zero voltage is fed via contacts 6 and 7 of the Touchguard relay RL62-K to pin 14 (NOT SAFE 1) on the board; thus the SAFE 1 input to the AND gates is High. The other inputs (NOT EXT, NOT ACC, NOT STOP) are all open circuit and so are High permanently, while the CW and CCW inputs are High so long as the Limit 1 switches are not operated. Thus each AND gate (D14-18, D21-25) gives a High output which switches-on TR1 and TR2, thereby allowing a control voltage of either polarity to pass.

Summing amplifier IC1 can be used to one of two modes; mode switching is accomplished by TR5 in the feedback loop of IC1, the switch-on or switch-off of TR5 being determined by AND gate D47-50. Under manual control the logic inputs to gate D47-50 are High so that TR6 is held in the cut off state. Thus TR5 conducts and IC1 has resistive feedback applied via RV1 and R23. For Arc Therapy operation, however, TR5 is cut off to increase the loop gain (see text 6.4).

The output of the summing amplifier IC1 is applied directly to comparator IC4 and via a unity gain inverter IC3 to comparator IC5. The inputs to IC4, IC5 at pin 3 are clamped by diodes D72, D74 so that only the positive inputs are accepted. Thus a positive control signal (c.w.) results in a positive voltage at IC5-pin 3 while a negative control signal results in a positive voltage at IC4-pin 3.

A negative-going ramp waveform from IC6 at 100/120Hz is applied equally to the other inputs (pin 2) of IC4 and IC5. The ramp is generated as follows: 40 volts a.c. at 50/60 Hz is fed to pins 17 and 18 on PWB62-A from mains transformer T1 on Level 2, and is applied to the full-wave rectifier D82, D83. The resulting negative-going half-sinewaves at 100/120 Hz are applied to TR17 which therefore conducts for most of each cycle but is cut off for a brief instant at each positive (zero volts) peak. This action produces short negative-going reset pulses at 100/120 Hz from TR17 collector which are applied via D81 to pin 2 of ramp generator IC6. Each reset pulse causes IC6 to conduct heavily so that the output at IC6-pin 6 is driven rapidly positive, charging-up C12 until it is clamped at 9 volts by ZD11, ZD12.

At the end of the reset pulse, TR17 conducts again, D81 is reverse-biased and C12 starts to discharge at a rate determined by R73, R75. Current flow at IC6-pin 2 now takes place in a reverse direction so the output voltage at IC6-pin 6 falls linearly towards zero until the next reset pulse occurs, thereby producing a negative-going linear ramp waveform (waveform A of 4513 390 0244). The rate at which the ramp voltage falls is adjusted by R75 so that the reset by TR17 occurs at about +0.7 volt, i.e. before it falls to zero. This deliberate offset from zero is introduced to prevent any output appearing from the motor-control system when the control input signal is at zero.

The output of the appropriate comparator (IC4 or IC5) consists of a train of pulses at 100/120 Hz, the width of each pulse being determined by the amplitude of the control signal at that instant. When the ramp voltage exceeds the control voltage at pin 3, the output at pin 6 is -15 volts, but when the ramp

voltage is less than the control voltage the output is switched to +15 volts. As the control voltage increases in amplitude, the point on the ramp waveform at which switching occurs moves up the ramp so that the width of the +15 volts pulse increases. The other comparator, which does not have a control signal applied to it because of the clamping effect of D72 or D74, produces a continuous output at -15 volts.

The +15 volts pulses from IC4 or IC5 are used to modulate the continuous pulses from a pulse generator IC10; this is an astable circuit comprising three gates of IC10 and is activated by the Motor Relay signal (zero volts) from TR9 collector. The output pulses at 5-10 kHz (see waveform B) are fed via D77 and D78 to the driver stages TR14, TR16 where they are modulated by the controlled-width +15 volts pulses from IC4 or IC5. Thus the appropriate driver stage TR15, TR16 (c.w.) or TR13, TR14 (c.c.w.) produces bursts of 5-10 kHz pulses coincident with the modulation pulses at 100/120 Hz and these are used to trigger the Thyristor Power Control board PWB62-B (text 4.7).

4.6.2 Motor Relay Circuit

The Motor Relay circuit is a safety circuit on PWB62-A which is enabled when NOT SAFE 1 (pin 14) and NOT SAFE 2 (pin R) are both at zero volts. As a result the outputs of IC8-pin 12 and IC9-pin 4 are High, giving a Low output from IC10-pin 12. Thus IC9-pin 9 is High and TR9 conducts, thereby energising the Motor relay RL62-B; the circuit is completed externally via D5 etc. for manual control of Gantry movement or via D4 etc. for Arc Therapy control.

When the contacts of RL62-B close, a 240 volts a.c. supply is applied to energise relay RL62-A (Movements). This action connects the 240 volts a.c. supply to the Thyristor Power Control board PWB62-B. If either of the NOT SAFE inputs becomes an open-circuit, (i.e. touchguard actuated or 'movements enable' switch released) IC10-pin 12 goes High; thus the output at IC9-pin 9 goes Low, TR9 is cut-off and RL62-B (Motor Relay) is de-energised.

4.6.3 Motor Relay and Clutch : Delayed De-energising

A Delay circuit on the board is used to delay the de-energising of the Motor relay RL62-B, and hence the clutch, until the motor has stopped rotating under the normal dynamic braking action. The SAFE 1 and SAFE 2 outputs of IC8-pin 12 and IC9-pin 4 are connected via D57, D58 and C2 to TR8 base. A change of state from High to Low will immediately turn-off TR8, and C2 will then charge via R33 until TR8 turns-on again after a delay determined by time constant C2, R33. During this delay the input to IC9-pin 14 is High, giving a Low from IC9 pin 12 which overrides the output from IC10-pin 12. Thus TR9 is held conducting longer and the de-energising of the Motor relay RL62-B and the clutch are suitably delayed.

4.6.4 Motor Current Limiting Circuit

A Current Limiting protection circuit for the motor is provided on PWB62-A. For this the voltage across R2 in the current return path from the motor armature is fed to pins 2 and B of PWB62-A and applied across a photocoupler protected by zener diode ZD8. The current flow through the photocoupler determines the

current in RV2, R49 and hence establishes the output voltage of IC2 (Current Limit). When this current is small, the output at IC2-pin 6 is at +10V (limited to this by ZD7) so diodes D70, D71 are reverse-biased and have no effect on the speed command signal at pin 3 of IC4 or IC5. As the armature current increases so does the excitation of the photocoupler until, at a level set by RV2, the output of IC2-pin 6 goes negative, causing D70 and D71 to be forward-biased and connect the negative voltage to pin 3 of IC4 and IC5. Thus the speed control signal is reduced in amplitude and is limited.

4.6.5 Limit 1 Switches

The LIMIT 1 switches complete a circuit which permits rotation of the associated motor only when zero voltage is applied through them to NOT CW (pin P) and NOT CCW (pin 13) on the board. The outputs of IC8-pins 7 and 9 are then High and are applied to a series of diode logic AND Gates. If a LIMIT 1 switch is actuated by overtravel of the Gantry the corresponding input at pin P or pin 13 goes High; thus the output from IC8 at pin 7 or pin 9 goes Low. This logic signal is applied to inputs D15 or D22 of the diode AND Gates and causes the output of the appropriate Gate to go Low, thereby switching-off the associated FET (TR1 or TR2). This action cuts-off the control signals for that particular direction of rotation, so preventing further rotation in that direction. However, control signals for the opposite direction of rotation are not prevented because zero voltage is still applied via the other LIMIT 1 switch. This enables the Gantry to be rotated out of the actuated condition of a LIMIT 1 switch.

4.6.6 -15V Power Failure Protection

This circuit prevents trigger pulses from reaching the thyristor power control board if the -15V power supply fails. In normal operation, current flows from 0V to the -15V supply via D84, ZD14 and R81. TR18 is biased off by the forward voltage drop across D84. If the -15V supply fails, TR18 base is pulled up via R82 and TR18 conducts, grounding the thyristor drive pulses via D85 and D86.

4.6.7 Other Functions

The other circuits used on PWB62-A are the speed control input at pin 8 (ACC) and the NAND Gate inputs at pin 12 (NOT PI) and pin N (NOT ACC), all of which are used for Arc Therapy (see text 6). The inputs at pin M (NOT EXT) and pin 7 (EXT) are used when an external control is employed, e.g. automatic set-up in conjunction with the Philips 'Vericord' system.

4.7 THYRISTOR POWER CONTROL BOARD : PWB62-B

- Circuit diagrams : 4513 390 0354, Gp.130-1 - Thyristor power control board
  4513 390 0724, Gp.130-1 - Transformer PWB

On this board two sets of thyristors CSR2, CSR3 and CSR1, CSR4, together with the common diodes D1, D4, form two half-controlled, positive output, thyristor bridge-rectifiers which are fed from the 240 volts, 50/60 Hz mains supply via pins 8 (etc.) and 20 (etc.). Each bridge provides about 1 kW of power for independent control of c.w. or c.c.w. rotation of the motor. For c.w. rotation,

the phase-controlled pulse trains at 100/120 Hz from the Motor Control Board are applied via pin A to two separate trigger transformers T1 and T2 (only one half of each transformer is used for each direction of rotation). The trigger waveforms from T2A, T1B are applied to their associated thyristors which, when forward-biased, alternately conduct a portion of each positive half-cycle of the 240 volts mains waveform as determined by the phase of the trigger pulses. The resulting unidirectional pulses of power at 100/120 Hz are used to drive the motor, and the motor speed is determined by the phase of the leading pulse in each pulse train (see waveforms A and B). For c.c.w. rotation the phase-controlled pulses are applied via pin 1 to trigger the other half of transformers T1 and T2. The flywheel diodes D2, D3 absorb the power overswing of the inductive load and ensure thyristor cut-off at the end of each half-cycle. Diodes D9, D10 are included to suppress transients.

5. CONTROL OF SMALL H.P. MOTORS

5.1 CIRCUIT DIAGRAMS

- Movements control system : 4513 329 0010, Gp.130, Sht.3
- Gantry circuit (part 2) : 4513 326 3000, Gp.130, Sht.2
- Motor Control (Small H.P. motors) : 4513 390 0344, Gp.130, Sht.1

5.2 CONTROLS AND RELAYS

The three small horse-power motor control circuits for the radiation head movements are all identical; the following table gives the main component references for each circuit:

Movement	Thumb-wheel control	Control relay	Motor control board	Limit switches	
Radiation head rotation	TWS-C	RL62-C	PWB62-C	SX (c.w.)	SW (c.c.w.)
Inner diaphragm Field 'Y'	TWS-A	RL62-E	PWB62-E	SAA (fully open)	SBB (fully closed)
Outer diaphragm Field 'X'	TWS-B	RL62-D	PWB62-D	SY (fully open)	SZ (fully closed)

5.3 MOVEMENTS INTERLOCKS

The selected motor control circuit becomes operative only when its control relay is energised. This requires the following interlock conditions to be met:

- The 'movements enable' switch on the Movements Controller must be operated;

- The 'movements' switch linked to the thumbwheel control must be operated;
- A Gantry Limit 2 switch must not be actuated;
- A touchguard must not be actuated;
- When a Shadow Tray Assembly is fitted to the radiation head it must be locked in position;
- All STOP MOTORS emergency circuits (including those on the Patient Support System) must be in the reset state.

When the appropriate control relay is energised, ±24 volts d.c. supplies are connected to the associated Motor Control board. R11 and C9 are connected across the winding of relay RL62-C to minimise relay contact arcing and improve the dynamic braking of the treatment head rotation movement.

5.4 SPEED AND DIRECTION CONTROL

The control voltage originates from a potentiometer forming part of the thumbwheel control. The voltage at the wiper of this potentiometer is buffered and applied to pin 2 of the associated Motor Control board. The polarity determines the direction of motor rotation, the amplitude determines the speed.

For a positive control voltage, the motor control circuit produces repetitive positive-going pulses at 100/120 Hz, resulting in c.w. rotation of the motor. A negative control voltage produces repetitive negative-going pulses, causing c.c.w. rotation. The width of the pulses and hence the speed of the motor, depends primarily on the magnitude of the control voltage, but also on a speed-correction voltage derived by sampling the back e.m.f. and armature current of the motor.

The pulse power is fed to the motor armature via diodes D1 or D2 (according to polarity) and the normally closed contacts of the CW and CCW Limit switches. The motor current return path is completed via pins 13, 14 of the Motor Control board where the current is converted into an equivalent voltage proportional to the armature losses and used to derive the back e.m.f. of the motor for speed control purposes.

5.5 MOVEMENTS LIMITS

When the movement reaches one of its two limits for c.w. or c.c.w. rotation of the motor, the appropriate limit switch is actuated. This action removes the power from the motor and short-circuits the armature by means of D3 or D4, thereby providing dynamic braking for the motor. Back-to-back zener diodes ZD1 and ZD2 across the motor armature protect the drive transistors against the back e.m.f. generated in the period when the limit switch contacts open but have not yet made contact with the opposite pole.

5.6 SMALL H.P. MOTOR CONTROL BOARD

- Circuit diagram : 4513 390 0344, Gp.130-1

This board is used to control the small h.p. (24 volts) motors. Its circuit consists basically of a switched-mode bipolar stage which applies power to the motor armature. Power control is achieved by pulse-width modulation at a fixed frequency (400 Hz in this case). Speed feedback is obtained from the motor voltage by compensating for the voltage loss due to the motor armature current.

The board adjusts the speed and direction of the associated motor in accordance with control signals from a Movements Controller. A control signal originates as a d.c. voltage from the appropriate lever-operated potentiometer control and the signal is then applied to its Motor Control board where it is combined with a speed-sensitive correction voltage provided by the back e.m.f. of the motor.

TR1, TR2 on the board are series regulators which convert the input ±24 volts supplies at pins 19, 20 to stabilised ±14 volts supplies. The board carries the following potentiometer controls.

RV1 : Set current feedback

RV2 : Set maximum speed

RV3 : Set gain

RV4 : Set current limit

The control signal from the thumbwheel control is applied to pin 2 of the board and results in a motor voltage at pin 11 etc. This voltage is fed back via pin 8 and resistor R43 to the inverting input of IC4a which has a gain of 0.37. As the non-inverting input of IC4a is connected to zero volts, the inverted output at IC4a-pin 1 represents the motor voltage related to zero volts.

The motor armature current is fed back via pin 13 etc, and its voltage equivalent is developed across R12; this voltage is applied to RV1 which is adjusted to set the required current feedback level. Since

$$V(\text{back e.m.f.}) = V(\text{motor}) - IR(\text{armature}),$$

the true back e.m.f. is extracted by combining the motor voltage feedback (via IC4a and R31) with the voltage equivalent of the armature current (via R30). The resultant speed-sensitive voltage at IC4b-pin 7 is applied in opposition to the control voltage derived via IC5, and their summation at the junction of R28, R35, R37 is a speed-corrected reference voltage which is related to zero volts at IC3b.

The inverted output at IC3b-pin 7 provides the reference d.c. level for the pulse output from the bipolar stage IC3a, IC1b, and is applied to their inputs. A ramp waveform from a ramp generator is applied to the other input of IC3a, IC1b.

The ramp waveform generator IC2 is not synchronised with mains frequency. It has three possible frequencies of operation: 100 Hz, 400 Hz or 1 kHz, selected by a link. In this case the link should be set to 400 Hz.

The ramp generator consists of an amplifier stage IC2a and an integrator IC2b which integrates from about +10 volts down to nearly zero, then resets to the +10 volts level. The first stage IC2a operates as a bistable level detector that clamps the ramp voltage between a safe datum of 0.7 volt and a maximum level of about 10 volts as follows. The voltage at IC2a-pin 6 is +1.4 volts (set by ZD7). When the output at IC2a-pin 7 is positive (+14 volts) the voltage at its positive input (pin 5) is the sum of the integrator output voltage V(integrator) and the forward voltage drop across ZD8 (0.7 volt). IC2a changes state as soon as:

$$V(\text{integrator}) + 0.7V = 1.4V$$
$$\text{i.e. when } V(\text{integrator}) = 0.7V$$

At the same time the positive input at IC2a-pin 5 becomes V(integrator) -9.1V by the zener diode action of ZD8. IC2a changes stage again as soon as:

$$V(\text{integrator}) + 9.1V = 1.4V$$
$$\text{i.e. when } V(\text{integrator}) = 10.5V$$

Bipolar pulse-width modulation is obtained by applying the reference d.c. voltage to the ramp waveform at IC3a and IC1b. When the reference level is positive and greater than the time-varying amplitude of the ramp voltage, the output at IC3a is a positive-going pulse; when the reference level is negative and greater than the amplitude of the ramp voltage, the output at IC1b is a negative-going pulse. The pulse width therefore is determined by the penetration of the ramp waveform beyond the reference level. The pulses are applied at 400 Hz to the driver stages TR5, TR7 and TR6, TR8. The output pulses of the board at pins 11, 12 are fed out to the motor.

A drive-current limiting stage is fitted, comprising IC1a and its associated components. The input signal level of IC1a is set by RV4 and its output varies between ±0.7 volt. A change in output voltage switches TR3 at high speed; its collector voltage therefore varies between -14 volts and zero and this is used to switch TR4, an FET controlling the driver stage of the board. Thus the driver stage (TR5, TR7 and TR6, TR8) is switched off if the motor current exceeds a preset level, irrespective of polarity. By positive feedback via R8 a small amount of hysteresis is introduced into the frequency of the circuit action so as to reduce the current ripple to an acceptable level.

6. ARC THERAPY CONTROL

6.1 BRIEF DESCRIPTION

When an Arc Therapy treatment is being given, the Gantry rotates over a preset arc while the patient is being irradiated, and the degrees of arc traversed per unit dose are maintained constant. Parameters which are set prior to treatment (in addition to the normal therapy settings) are:

TECHNIQUE : Select Rotation clockwise (ROTN CW) or counter-clockwise (ROTN C-CW).

ARC START : Enter 'Start' angle for the Gantry.

ARC STOP : Enter 'Stop' angle for the Gantry.

For a flat field, the set dose is delivered over the set arc of Gantry rotation. For a wedged field using the motorised wedge filter, the set dose is delivered over the set arc only for a 60° wedged-field treatment. For other wedge angles, two set dose values are entered: a 'wedge' dose and a 'total' dose. During treatment, first the 'wedge' dose is given over the set arc, followed by a brief pause at the 'Stop' angle during which the wedge is automatically withdrawn from the field. Then an unwedged field is given over the return arc to the 'Start' angle to complete the 'total' dose. Whenever the auto-wedge filter is in motion, the electron gun is automatically switched to the 'standby' mode and the PRF Generator output is inhibited.

6.2 MOVEMENTS INTERLOCKS

- Circuit diagrams : 4513 329 0010, Gp.130, Shts. 1 and 3

When the basic movements interlocks are complete (see Chapter 3) Touchguard relay RL62-K is energised. Its contacts 12-13 then connect +24 volts to signal the 'Movements Ready' condition to the TCC (PWB76-P, pin Mb). They also connect +24 volts to the Terminate, Interrupt and Start chain of switches, through to relay RLF on PWB76-AA. Relay RLF can then be energised by pressing the treatment START push-button, provided that the TCC 'Treatment Enable' interlock (PWB76-P, pin 6b) governing the return circuit of RLF is complete. Contacts 6-7 of RLF will then complete the treatment H.T. interlocks, while contacts 9-10 hold the relay energised.

6.3 LOGIC CONTROL OF MOVEMENTS

When Arc Therapy operation has been selected at the TCT, and the treatment START push-button has been pressed, +24 volts are fed from the TCC (pin 15b of PWB76-E) to relay RL62-B (Motor Relay). At the same time, the +12 volts output from Pin Wb of PWB76-E changes to zero, thus putting a logic low signal on pins 12 (NOT PI) and N (NOT ACC) of PWB62-A. The Low signal is also applied via a diode to pin R (NOT SAFE 2) and via RL62-K contacts 6-7 to pin 14 (NOT SAFE 1) and so energises relay RL62-B (Motor Relay) as described for manual control (text 4.6.2).

The effect of the NOT ACC Low signal is to inhibit NAND gate IC7 on PWB62-A. Thus the output at IC7-pin 12 changes from Low to High. This change is applied to D32 and gives a High output from AND gate D30-D34 (assuming that its four other inputs are also High). This switches-on TR3, so allowing the dose-rate analogue of the motor-speed signal at pin-8 (ACC) to pass to the summing amplifier IC1.

When NAND gate IC7 is inhibited by the NOT ACC Low input, the output at IC7-pin 9 applies a Low signal to diode D23 of AND gate D21-D25, so producing a Low

output which switches off TR2 and effectively disconnects the c.c.w. manual control signal from the summing amplifier IC1. Likewise, this Low signal is applied to diode D16 of AND gate D14-18 which therefore produces a Low output. This switches-off TR1, thus disconnecting the c.w. manual control signal from the summing amplifier IC1.

6.4 DIRECTION AND SPEED CONTROL

A voltage analogue of the monitored dose-rate is available at the Dose Channel 1 Integrator board PWB76-H in the TCC. This signal is fed to the Moving Treatment Controller board PWB76-F, where it is integrated over a 40 ms period and sampled for a time proportional to the set degrees/unit dose. The resulting output voltage is proportional to the required rotational speed of the Gantry. This signal is fed out as the control voltage to pin 8 (ACC) of the Motor Control board PWB62-A to control the speed of Gantry rotation. 'Direction-of-rotation' signals at PWB76-F select the appropriate polarity for the control voltage.

When the treatment START push-button is first pressed, a dose-rate signal will not result immediately because of the 6-second gun delay (see Chapter 9). Hence, the Gantry will not rotate at once. When the delay has elapsed, rotation will start and any variation in the dose-rate signal will be matched by a variation in gantry rotational speed.

The logic signal for the arc therapy mode logic is taken from PWB76-E, pin Wb to PWB62-A (text 6.3). The input at pin 12 (NOT PI) acts via NAND gate IC8-pin 4 and inverter TR6 to switch-off TR5 and thus brings R43, C5 into use. These components change the motor control law from 'proportional' to 'proportional integrating' and increase the loop gain of IC1; this improves the sensitivity of the circuit to small changes in the dose-rate signal. The rest of the motor control circuit operates as for manual control.

During Arc Therapy the p.r.f. is automatically selected by the microprocessor so that the Gantry does not rotate at excessively high or low speeds. Thus PWB76-P in the TCC provides signals to the P.R.F. Generator on PWB76-CC so that it supplies a p.r.f. of 300 p.p.s. in the range 0.1 to 0.99 degrees per unit dose and a p.r.f. of 150/180 p.p.s. in the range 1.00 to 1.99 degrees per unit dose. These p.r.f. rates are independent of the position of the PRF selector; (see Drg. No. 4513 329 0010, Gp.130, Sht.2).

6.5 TERMINATION OF ARC THERAPY

When the dose delivered reaches the dose set on the TCT, the radiation output is terminated instantly and the interlock circuit to relay RL62-B (Motor Relay) is broken (see text 6.3), so the gantry rotation stops at the same instant. If a fault should occur, the situation for abnormal termination applies, therefore gantry rotation and irradiation stop immediately.

7. BEAM ABSORBER CONTROL

- System diagram: 4513 329 0730 Gp.130-1

The beam absorber control unit is mounted on the left-hand side of the beam absorber frame (at 0° gantry angle looking from the radiation head end) and is accessible by removing the gantry left-hand side cover. It is fed with a 240V a.c. supply taken from 2/T1 of contactor 60-D (Stop Motors - see 4513 329 0010 Gp.130-3 in Vol.3). This supply normally comes on when SUPPLIES ON is selected at the TCC engineer's panel, and can be isolated by opening movements control circuit breaker CB10. The supply is protected by fuse FS1 on entry to the control unit.

Relays RL19-C and RL19-D energise to switch the 240V a.c. supply to drive the beam absorber motor in the retract and extend directions respectively. The energisation of either relay releases the brake.

Relays RL19-C and RL19-D are controlled by the BEAM ABSORBER switch on the movements controller via relays RL19-B and RL19-A respectively. RL19-E is in parallel with the movements control touchguard relay RL62-K (see Chapter 2). The contacts of RL19-A, RL19-B, RL19-E and the beam absorber limit switches are interlocked for fail safe operation and to prevent beam absorber motion in the extend direction with a touchguard switch operated.

8. MAINTENANCE INFORMATION

8.1 PREVENTIVE MAINTENANCE

Routine checks of Gantry movements are scheduled in Volume 1, Chapter 3. Of particular importance is a regular (weekly) check that movement from the Movements Controller cannot be achieved by operating a movement thumbwheel control alone, or by repeatedly pressing the 'movements enable' switch, but that both controls must be operated at the same time.

8.2 MECHANICAL ADJUSTMENT OF MOVEMENT CONTROL FOR ZERO OUTPUT SIGNAL

Before setting-up a movement, check that the unactuated movement control lever is set to its mechanical centre ('off' position), then connect a multimeter from the output of each control (pin F or IC1 pin 6) to zero volts. If the measured voltage is greater than 100 mV, slacken off the mechanical coupling of the potentiometer shaft to the lever. With the lever still at mechanical zero, adjust the potentiometer shaft to give zero ±0.1 volt on the multimeter; then tighten the coupling, taking care not to disturb the zero setting.

8.3 SETTING-UP THE LARGE H.P. MOTOR CONTROL BOARD

Type 4522 117 0400 or 4513 390 0244 (interchangeable types)

This is used for board PWB62-A (Gantry rotation) only. Set up its controls in the following order (refer to Fig. 2 for control layout):

RV3 : Set Offset

With no movements enabled, connect a multimeter between test point 1A/K and zero volts (pin 21). Adjust RV3 on the board to give zero ±0.01 volt on the multimeter.

RV2 : Set Current Limit

The current limit, to be meaningful, should be set up with the motor stalled. The method suggested is as follows:

(1) Connect a multimeter, set to 10 amp. d.c. range, in series with terminal 2 of the Gantry Drive motor and its connection to PL60C-L.

(2) Prevent Gantry movement by inserting the gantry locking pin (see Chapter 2).

(3) Ensure that RV2 is set fully counter-clockwise before starting. Enable the Gantry movement by pressing the 'movements enable' switch on the Movements Controller, then slowly and carefully move the GANTRY ROTATION control lever into the clockwise movement sector. The Gantry Drive motor will attempt to rotate the Gantry but will be restrained by the locking pin. Gradually move the control lever until the motor current stabilises in the stalled condition.

CAUTION

DO NOT MAINTAIN THE STALLED CONDITION FOR MORE THAN 10 SECONDS AT A TIME, OTHERWISE THE MOTOR SERIES RESISTOR MAY BE DAMAGED.

(4) While holding the control lever in the stalled position, get a colleague to adjust RV2 on the board rapidly to give a multimeter indication of 4.5 amperes, then release the control lever. The current limit is now set.

(5) Remove the gantry locking pin.

RV1 : Set Gain

With the movement enabled, increase the gain by turning RV1 clockwise until the motor starts to hunt, then decrease the gain by 2 turns. Take the movement over its full range of travel and check that hunting does not occur in either direction. If it does, reduce the gain by another turn, then recheck.

8.4 CHECKING THE THYRISTOR POWER CONTROL BOARD

Type 4522 117 0020 or 4513 390 0354 (interchangeable types)

This is used for board PWB62-B (Gantry rotation) only. The board does not require any adjustment. If it is replaced by another, check the appropriate movement over its full range of travel and ensure that the speed changes smoothly.

8.5 SETTING-UP THE SMALL H.P. MOTOR CONTROL BOARD

Type 4522 117 00107-9 or 4513 390 0344 (interchangeable types)

These are used for boards PWB62-C, D, E. Set up each board as follows (refer to Fig. 2 for control layout):

- Check that the link on the board is set to 400 Hz position.
- Set the four potentiometer controls RV1, RV2, RV3, RV4 fully counter-clockwise.
- Connect an oscilloscope to the board:

  Y input to TP2 (Y-sensitivity = 0.5 V/cm),

  Trigger to TP1 (timebase speed = 1 ms/cm).

NOTE

On machines fitted with the assisted set up and/or asymmetric diaphragm options, the procedures for setting up the small H.P. motors control boards are different to those given below. Refer to the appropriate supplement to this service manual for details.

RV1 : Set Current Feedback

Depress the 'movements enable' switch on the Movements Controller, then move the appropriate control lever to give about one-tenth of maximum speed. Adjust RV1 on the board for minimum amplitude of the oscilloscope waveform ('A' in Fig. 3) in the region indicated.

RV2 : Set Maximum Speed

Move the control lever to its maximum speed position. Adjust RV2 on the board to increase the motor speed until the oscilloscope waveform reduces to a minimum amplitude, as at 'B' in Fig. 3; then give RV2 two extra full turns beyond this.

RV3 : Set Gain

Reduce the motor speed with the control lever until the oscilloscope waveform is as shown at 'C' in Fig. 3. Adjust RV3 on the board until an oscillation is seen on the waveform as shown at 'D' in Fig. 3. Reduce the gain until the oscillation just ceases, then give RV3 two extra full turns in the same direction.

RV4 : Set I Limit

Leave R4 on the board at the minimum (fully counter-clockwise) position. The current limit is about 7 amperes at this setting.

* * * * *

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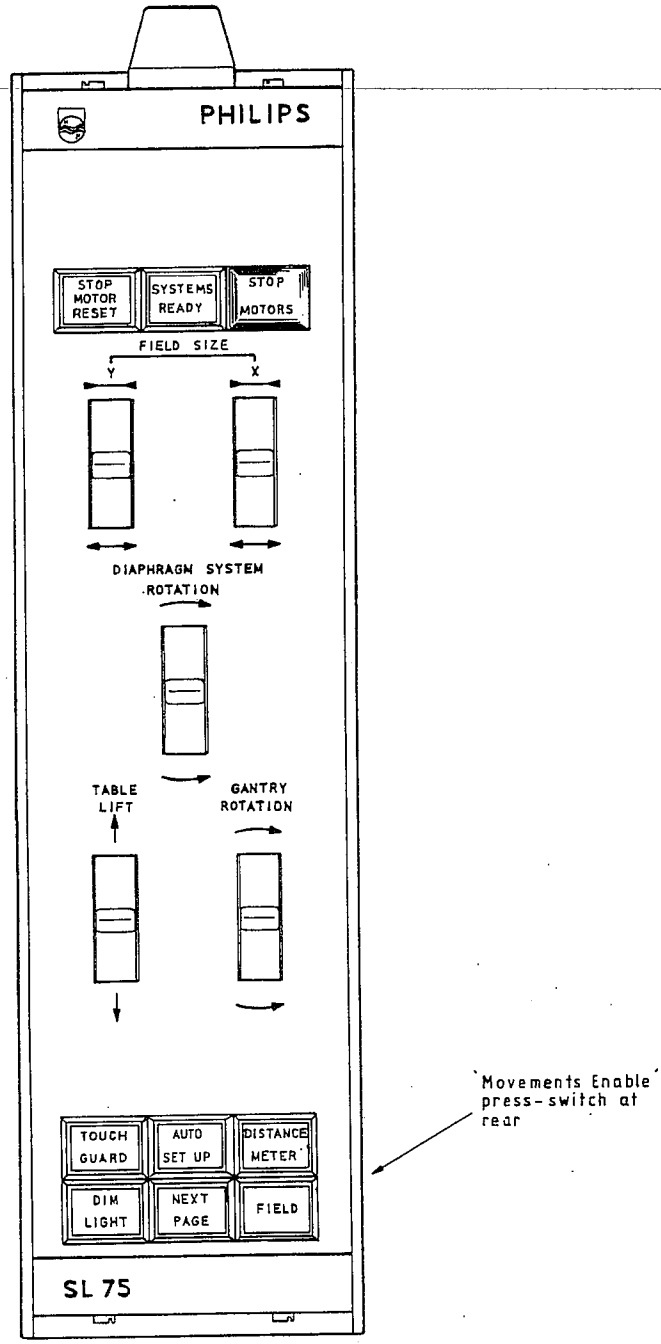

Figure 1: Movements Controller - control panel

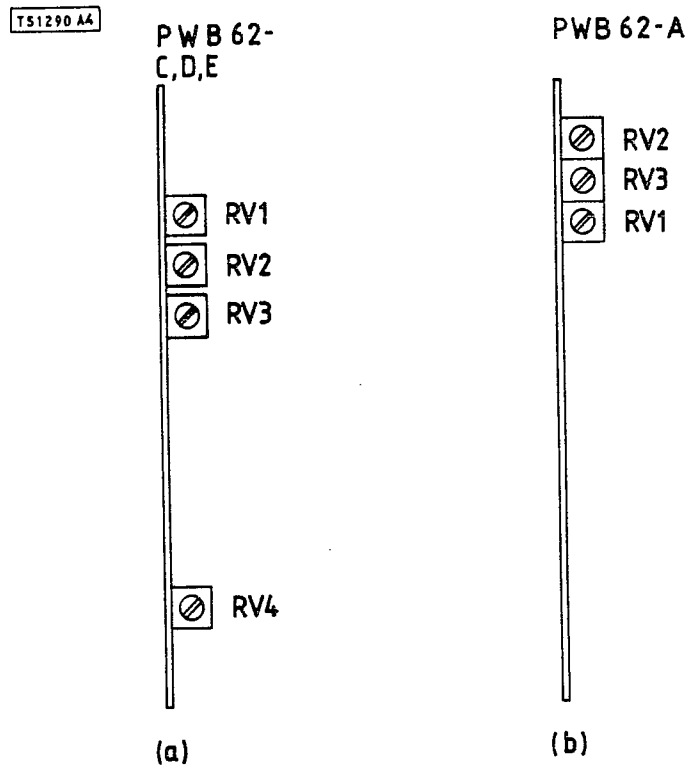

Figure 2: Layout of Control Potentiometers on the Motor Control Boards

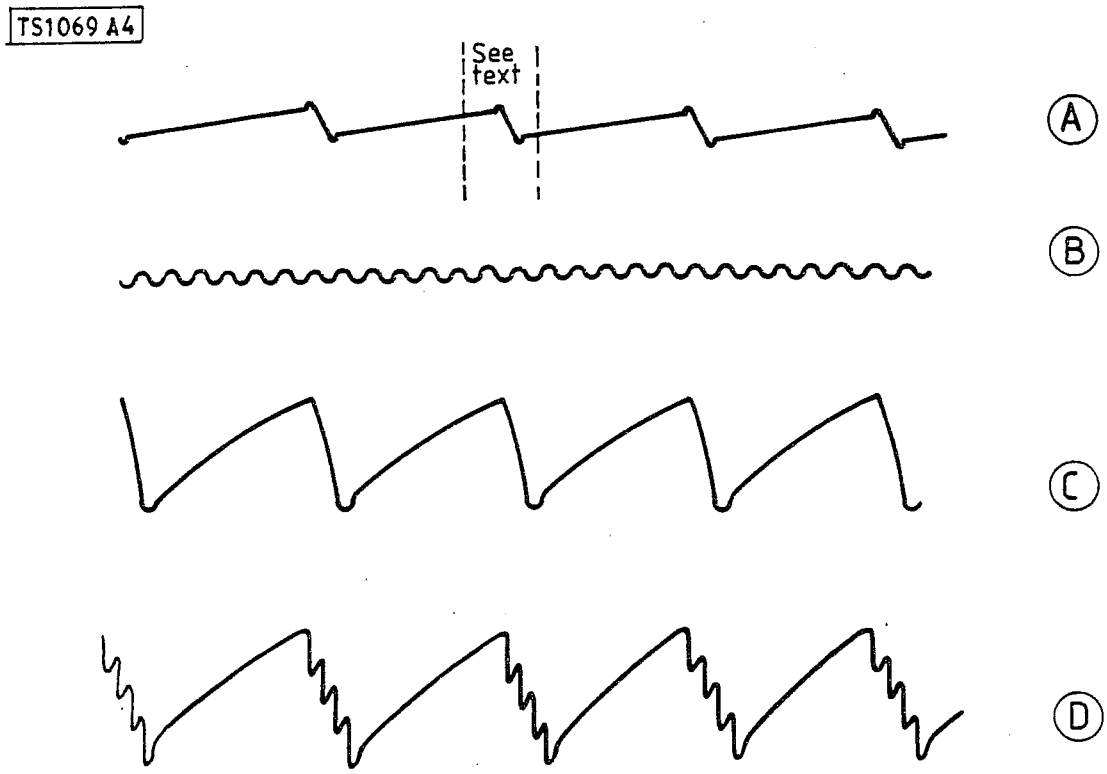

Figure 3: Waveforms for Small H.P. Motor Control Board

Chapter 11: WATER COOLING AND PRESSURISED AIR SYSTEMS

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1. WATER COOLING SYSTEM

The water cooling system supplies temperature-controlled water to six water circuits in the Linac:

- H.T. transformer;
- Accelerator waveguide and a.f.c. cavity block;
- Isolator and pulse transformer;
- Focus coils;
- Target;
- Magnetron.

1.1 SYSTEM DESCRIPTION

A Water Cooler, incorporating a pump and refrigerator, is used to provide a recirculating supply of temperature-controlled water for the Linac. The Water Cooler controls the temperature of the inlet water to the machine to ±1°C. The controlled inlet temperature can be set anywhere in the range 15°C to 30°C but normally it is set to near the ambient temperature of the treatment room, for example, 2°C less than ambient. If the water temperature becomes too high, a thermal switch in the interlock circuit operates to inhibit operation of the Linac.

The water supply from the Water Cooler enters the Linac through the isolating tap at the base of the Gantry Support Frame Assembly and is then fed via a flowmeter (0-40 l/min.) and a pressure gauge (0-100 p.s.i., or 7 bar) to the H.T. transformer and to the Gantry. The water is fed to the Gantry (and returned from it) using flexible hosepipes. These are routed from the inlet/outlet points so far described, across to the back of the structure and upwards over a broad saddle. From here, the semi-free hoses hang down the front of the structure and are grouped together by a cable guide, from where they hang with a slight droop as they are taken to the back of the structure again to pass through the axis of the rotatable gantry to the various water circuits on its other side.

In the Gantry the water is fed to two inlet manifolds which serve five water-cooling circuits. The inlet of each water circuit contains a flow controller (CONSTAFLO) which maintains a nearly constant flow of water through the component being cooled. At the outlet of each water circuit is a TRUFLO switch which is an electrical switch that operates should the flow of water fall below a minimum rate. The five water outlets are subsequently combined by two outlet manifolds from which two pipes feed the water back through an isolating tap to the Water Cooler for recirculation.

The six water flow switches, and a water temperature relay in the Water Cooler, are included in the electrical H.T. interlock chain so that, unless the flow is correct in each circuit and the water temperature is correct, H.T. cannot be

switched on (see Chapter 3 : Interlocks). One of two fault indicators, WATER FLOW and WATER TEMP, on the engineer's panel of the TCC lights up if the associated interlock is broken.

1.2 WATER-FLOW CONTROL DEVICES

The CONSTAFLO flow controllers are set to give the maximum flow rates listed in Table 1 (Note: 1 gallon = 4.55 litres).

Since any small particles in suspension in the recirculating water system will normally be trapped in the CONSTAFLO devices, periodic inspection is necessary. Instructions for the removal of a CONSTAFLO for inspection and cleaning are given in text 2.2.

1.3 WATER-FLOW SWITCHES

When water flows through an orifice a pressure difference is obtained across the ends. The TRUFLO water-flow switch utilises this pressure difference to operate a flexible diaphragm which controls a plunger-operated microswitch. The orifice is calibrated for a pressure drop of 2 lb/in^2 at the required flow rate. If the flow rate falls below the calibrated level, the pressure drop decreases and the microswitch is actuated to give a flow warning. When the flow rate is at the required level or higher, the microswitch is actuated to indicate a safe flow rate. Normally the flow rate is at least 25% above the critical level to allow for hysteresis effects. The calibrated flow rates for the six water flow switches are listed in Table 2.

Indication of a faulty water flow is given by illumination of the WATER FLOW lamp on the engineer's panel of the TCC. The faulty water circuit can then be identified from the appropriate indicator lamp near the flow switches at the rear of the gantry. If the fault is due to incorrect operation of a TRUFLO water-flow switch, replace it with a factory-tested switch. These can be obtained, on an exchange basis, from MEL at the address shown on Preliminary page 2.

1.4 WATER COOLER

The Water Cooler (Fig. 2) consists of a thermally-insulated fibre-glass tank, an air-cooled refrigerator and a water pump, together with associated controls and interlocks. The tank capacity is approximately 50 gallons (228 litres) and the water level in the tank should normally be not more than 2.5 cm below the return-pipe level.

The Water Cooler is capable of maintaining the inlet water supply to the Linac at ±1°C of the temperature set by its control thermostat under normal therapy conditions of machine duty. Furthermore, the capacity of the Water Cooler is sufficient for the Linac to operate continuously at full output with only a small temperature rise. If the temperature rises above the control level, however, and reaches the level set by the overtemperature thermostat (normally 5°C above the control level), the thermostat operates and de-energises an associated relay in the Water Cooler. The relay contacts then break the H.T. interlock circuit and light the WATER TEMP. indicator on the engineer's panel of

the TCC to signal the fault; also the red warning lamp on the Water Cooler is illuminated. If this fault indication occurs, check the water temperature in the Water Cooler tank to verify, then investigate the cause of the high temperature.

2. MAINTENANCE INFORMATION FOR WATER COOLING SYSTEM

2.1 OPERATIONAL CHECK

Proceed as follows:

(1) Ensure that all water taps in the system are fully open.

(2) Observe that the green indicator lamp on the Water Cooler is illuminated (see 'Note'). Switch on the mains supply to the Water Cooler pump by means of the SUPPLIES switch on the engineer's panel of the TCC.

NOTE

The refrigeration unit of the Water Cooler should be left switched on at all times (circuit breaker CB3 at Level 4 of the MCC).

(3) Open the top of the fibre-glass tank and ensure that water is being discharged into the tank from the return pipe. Check the water level in the tank; it should be about 2.5 cm below the return-pipe level.

(4) Check that neither the WATER TEMP nor WATER FLOW indicator is lit on engineer's panel of the TCC.

(5) Check from the Linac pressure gauge and flowmeter readings that the water pressure is in the range 50 - 60 psi (3.5 to 4.1 bar) and the water flow is about 30 - 33 litre/minute.

2.2 INSPECTION AND CLEANING OF CONSTAFLO FLOW CONTROLLERS

2.2.1 Preparation

Prepare to remove a CONSTAFLO from the Linac as follows:

NOTE

Because of the limited access in the area of the manifolds carrying the CONSTAFLO controller, a special short-handled offset spanner is recommended. This can be made up from an 8-inch adjustable spanner by grinding down the jaws to increase the maximum opening to 1.25 in. (31.75 mm).

(1) Swing back the Modulator cabinet and remove the Gantry side cover. Rotate the Gantry to a convenient position.

(2) Switch-off the machine by means of the SUPPLIES switch on the engineer's panel of the TCC.

(3) Shut off the water supply to the machine by closing the isolating taps at the base of the Gantry Support Frame Assembly.

2.2.2 Removal

Before removing a CONSTAFLO from the machine, note the orientation of the direction-of-flow arrow on its body, so that the device can be refitted correctly; also take precautions against water draining from pipes during and after removal of the CONSTAFLO (by suitably positioned buckets, etc.).

The method of removing each CONSTAFLO from its water circuit is as follows:

(1) H.T. transformer circuit:

Undo the water union at each end of the CONSTAFLO.

(2) Waveguide/a.f.c. cavity and Isolator/pulse transformer circuits:

Undo the input pipe and the two output pipes at their unions with manifold B, remove the two screws securing the manifold and remove it complete with the two CONSTAFLO units.

(3) Magnetron, Target and Focus Coil circuits:

Undo one input and three output pipes at their unions with manifold A, remove the two screws securing the manifold and remove it complete with the three CONSTAFLO units.

2.2.3 Servicing

Having gained access to the CONSTAFLO it should be serviced as follows:

(1) Remove the gland nut at the end of the device which is defined by the tip of the arrow; then remove the rubber insert, noting its orientation (the tip should point in the direction of flow).

(2) Inspect the rubber insert and orifice in the CONSTAFLO; clean as necessary. Replace the rubber insert (correctly positioned) in the gland nut and screw the body of the CONSTAFLO on to the nut; tighten fully.

(3) Reconnect the CONSTAFLO to the water pipes using PTFE tape on the joints. Ensure that the arrow on the body is positioned as noted previously. Check that the two water unions are adequately tightened.

(4) Open the isolating taps at the base of the Gantry Support Frame Assembly, then switch-on the Water Cooler. Check for water leaks at the reconnected CONSTAFLO. Remake joints if necessary.

2.3 TRUFLO SWITCHES

When fitting a TRUFLO switch, do not grip the switch bracket. Always use a spanner on the flats provided.

Do not use excessive pressure when making connection to the terminals. The TRUFLO switch is a precision factory-calibrated instrument, and any interference with its setting, or with the switch mounting brackets, could result in a variation of the flow-rate warning.

2.4 WATER COOLER MAINTENANCE

Preventive maintenance is given in the schedules in Volume 1, Chapter 3. The refrigerator requires no maintenance; if a fault occurs contact the nearest Frigidaire agent. For maintenance of other items, e.g. water pump, refer to the manufacturer's instructions.

3. PRESSURISED AIR SYSTEM

The pressurised air system (Fig. 3) maintains the rectangular waveguide between the magnetron and the input waveguide window at a pressure of 2.1 bar (30 p.s.i.) to prevent r.f. breakdown in the guide; the rectangular waveguide between the output waveguide window and the r.f. load is also maintained at the same pressure. The pressure is detected by the Guide Pressure switch SN which forms part of the main interlock chain (see Chapter 3). If the air pressure drops below 1.8 bar (26 p.s.i.), the contacts of SN open and break this interlock, thereby inhibiting Focus Start (RL60-B) and hence H.T. operation.

An air supply is required; either a foot pump or a filtered air-line supply will do. The air is applied via the Air Inlet valve at the hand side of the Gantry and the pressure is registered on the nearby pressure gauge (see Chapter 2, Fig. 3). When the pressurised air requires to be released from the rectangular waveguide, e.g. for removal of the magnetron, the air must be released through the filter on the air release tap at the rear of the Gantry.

* * * * *

FIG.1 REF	COOLING AREA	FLOW PER MINUTE			
		PH A		PH B/C	
		GALLONS	LITRES	GALLONS	LITRES
A	ACCELERATOR WAVEGUIDE & AFC CAVITY	2.5	11.4	3.0	13.6
B	MAGNETRON	1.25	5.7	1.5	6.8
C	FOCUS COILS	1.0	4.5	1.0	4.5
D	TARGET	0.75	3.4	0.75	3.4
E	ISOLATOR & PULSE TRANSFORMER	0.625	2.8	0.75	3.4
F	HT TRANSFORMER	0.625	2.8	0.75	3.4

Table 1: Flow Controller Settings

SWITCH CODE	COOLING AREA	FLOW PER MINUTE	
		GALLONS	LITRES
SK	ACCELERATOR WAVEGUIDE & AFC CAVITY	2.0	9.0
SH	MAGNETRON	1.0	4.5
SG	FOCUS COILS	0.75	3.4
SJ	TARGET	0.5	2.3
SL	ISOLATOR & PULSE TRANSFORMER	0.5	2.3
SE	HT TRANSFORMER	0.5	2.3

Table 2: Flow Switch Settings

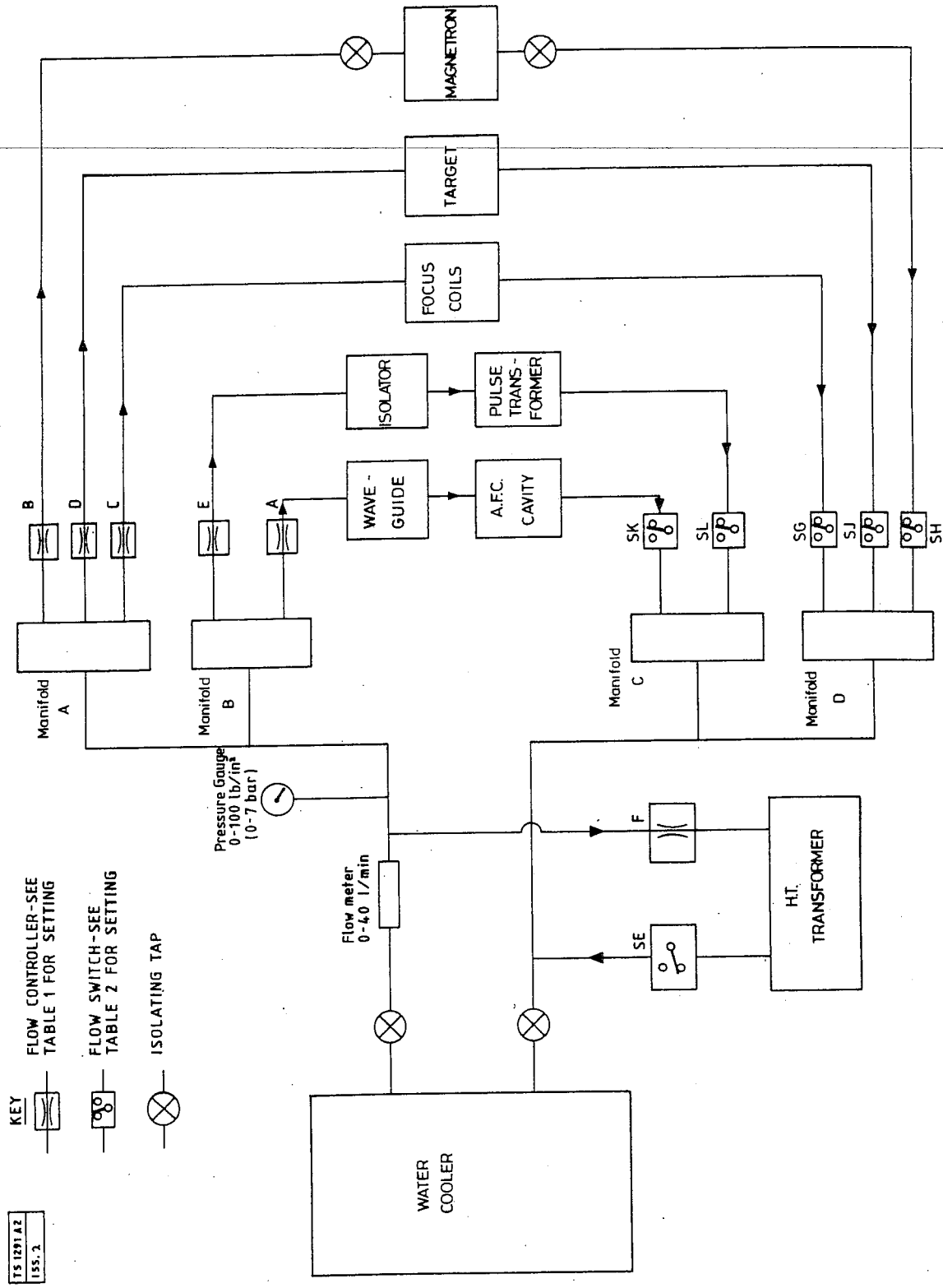


Figure 1: Water Cooling System

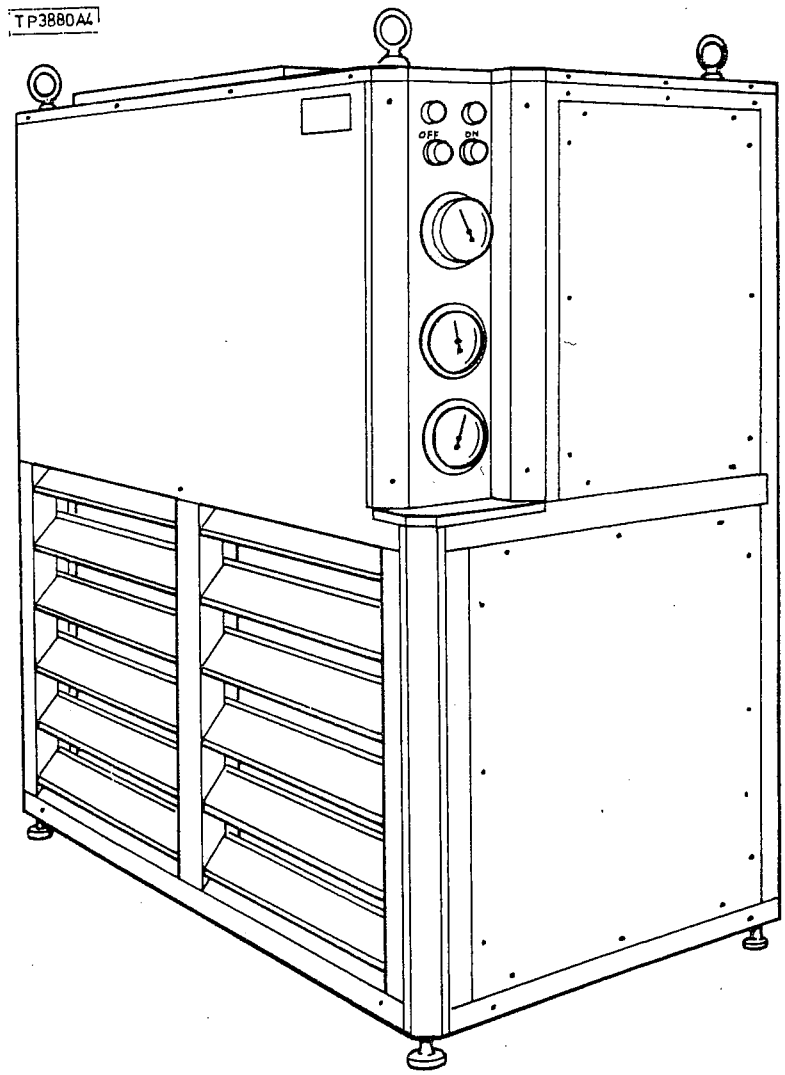
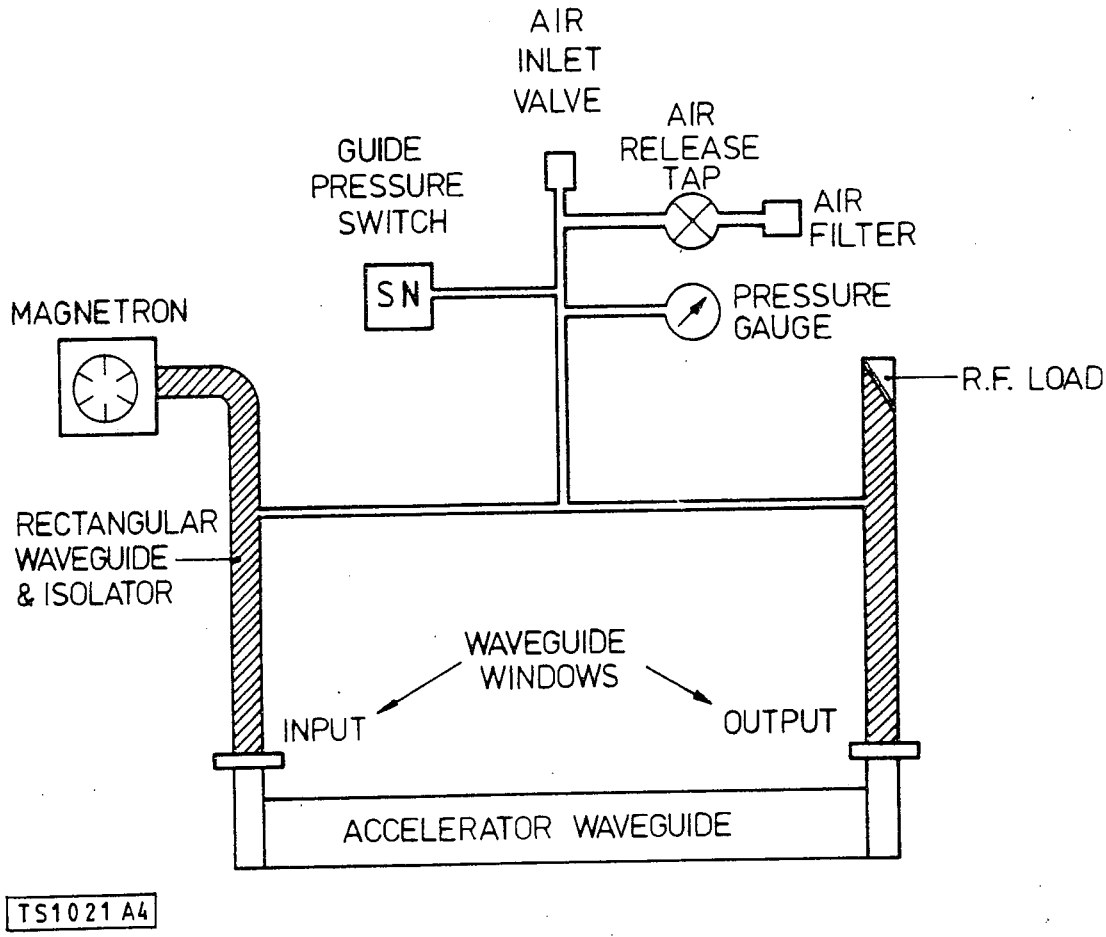


Figure 2: Water Cooler



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Chapter 12: X-RAY OUTPUT

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1. INTRODUCTION

This chapter reviews the various methods adopted to maintain acceptable X-ray output conditions from the Linac. It then decribes the way in which the various beam parameters are established and maintained, bearing in mind that the leakage radiation from the Linac must be kept to a low level.

2. BEAM CONTROL

2.1 SERVO-SYSTEMS FOR BEAM CONTROL

For correct X-ray output conditions, the electron beam trajectory through the bending system must be so directed that the emergent beam strikes the X-ray target perpendicularly. This condition is met by setting up a suitable bending field for the selected electron energy, and then providing a beam of electrons at that energy, correctly positioned, at the point of entry into the bending magnet field. Several servo-systems are employed to control the beam parameters:

- Beam energy : gun control servo-system
- Beam position in the plane of bending : 2R centring servo-system
- Beam position normal to the plane of bending : 2T centring servo-system

The beam energy is also affected by variations in the frequency of the magnetron microwave generator so an automatic frequency control (AFC) system is used to control this parameter.

2.2 CIRCUIT DIAGRAMS

- AFC system : 4513 329 0002, Gp.130
- 2R and 2T centring systems : 4513 329 0003, Gp.130
- Gun control system : 4513 329 0004, Gp.130

2.3 AUTOMATIC FREQUENCY CONTROL OF MAGNETRON

The two-cavity frequency discriminator in the gantry provides the automatic frequency control characteristic for this servo-system, and is set to centralise about the required operating frequency f_o by tuning-screws on the cavities. Potentiometer RV1 on PWB76-DD in the TCC is used to balance the two input channels for zero servo-error at frequency f_o. For details, see AFC system in Chapter 7 : Microwave System.

2.4 CENTRING SERVO-SYSTEM

Two servo-systems, 2T centring and 2R centring, control the position of the electron beam at the point of entry into the bending magnet field. The 2T

centring servo controls the beam position at right-angles to the plane of bending, while the 2R centring servo controls the beam position in the plane of bending. Potentiometer RV6 on PWB76-FF determines the nominal (reference) level of the control voltage for the 2T centring servo-system, on which are superimposed the servo-error signals from the multiplate ionisation chamber in the radiation head (see Chapter 9 : Beam Control System). RV6 on PWB76-HH determines the nominal level of the control voltage for the 2R centring servo-system. Both PWBs are in the TCC.

2.5 GUN SERVO-SYSTEM

This servo-system controls the beam energy by regulating gun filament current. Potentiometer RV6 on PWB76-JJ in the TCC determines the nominal (reference) level of the control voltage for the gun control servo-system, on which are superimposed the servo-error signals from the multiplate ionisation chamber in the radiation head (see Chapter 9 : Beam Control System).

2.6 BENDING MAGNET FIELD

The bending magnet is a permanent magnet with an adjustable shunt which is preset by the factory to give the field for the required energy. Although the field can be reset, if required, by means of two nuts at the end of the gantry arm, normally it should not be necessary to do this.

3. X-RAY FIELD SYMMETRY AND FLATNESS

3.1 INTRODUCTION

A comprehensive setting-up procedure for X-ray field flatness is given in Chapter 9. Normally, however, the maintenance of field flatness in the hospital will consist of occasional small adjustments to the field symmetry by adjusting the balance control RV1 on the appropriate servo-control board in the TCC (PWB's 76-FF/HH/JJ). The servo currents are displayed on the engineer's monitor in the Gun-I, 2R-I and 2T-I positions of the associated selector switch, as required. The method is as follows:

3.2 X-RAY FIELD SYMMETRY

(1) Using the equipment described in Chapter 9 for 'Setting-up X-ray Field Symmetry', position the ionisation chamber successively at G20 cm and T20cm, and check that, for a 100-unit dose, the dose at the two points agree within 1%. If not, adjust the gun-servo balance control RV1 on PWB76-JJ to achieve this symmetry and note the new gun current.

NOTE

When noting the centring servo currents in the GUN-I, 2R-I and 2T-I positions of the Engineer's monitor switch, the reading may not be steady due to the servo action. Therefore, note the maximum and minimum values over a period of several seconds and take their mean value as the reading.

(2) Disconnect the gun servo inputs by removing the coaxial plugs A and B on PWB76-JJ. Switch-on GUN and H.T., then adjust the gun servo Set Nominal control RV6 on PWB76-JJ to give the new gun current noted in step (1). Replace the coaxial plugs and recheck the symmetry at G20, T20 cm.

(3) Position the ionisation chamber successively at G9 cm and T9 cm then check that, for a 100-unit dose, the dose symmetry is within 1%. If not, adjust the 2R Balance control RV1 on PWB76-HH and note the new 2R centring current required to achieve symmetry. Switch-off H.T., then adjust the 2R Set Nominal control RV6 to give this new 2R current.

(4) Recheck the dose symmetry at both G20, T20 cm and G9, T9 cm, and make any necessary adjustment for symmetry to the appropriate RV1 Balance control.

(5) Position the ionisation chamber successively at A20 and B20 cm then check that, for a 100-unit dose, the dose symmetry is within 1%. If not, adjust the 2T Balance control RV1 on PWB76-FF and note the new 2T centring current required to achieve symmetry.

(6) Switch-off H.T., and adjust Set Nominal control RV6 to give the new 2T centring current noted in step (5), then recheck the symmetry at A20, B20 cm.

3.3 X-RAY FIELD FLATNESS

When the field symmetry has been set satisfactorily, the field flatness should be checked with the gun and centring servo-systems operating to maintain symmetry. If the desired flatness is not obtained, it may be necessary to make small corrections to the flattening filter to remove any small irregularities in the X-ray field (but first see Note).

NOTE

In the process of shaping the flattening filter, the danger exists that corrections for centring or energy errors are introduced into the filter. This should be avoided by ensuring that the least alteration from a symmetrical filter is made.

As a guide to correcting field-flatness faults, observe that small changes in gun filament current mainly affect symmetry at the edges of the X-ray field on the G-T axis, whereas centring current changes affect the central portion of the field, i.e. 10 x 10 cm region. Note also that small adjustments to centring controls 1R and 1T (on PWB76-LL in the TCC) may be necessary for symmetry following a gun filament change. If so, the leakage radiation should also be checked (text 4).

3.4 BEAM ENERGY

If the required field flatness cannot be obtained, it is possible that the beam energy is incorrect, although this should be defined by the bending magnet field which does not normally require adjustment. Incorrect beam energy affects the depth-dose characteristics in water so, if the appropriate facilities exist, this is a satisfactory way of checking energy (see below).

The energy of the X-ray beam (at 300 p.p.s.) can be established reasonably well from measurements of the 50% depth-dose contour in water. For a 10 x 10 cm field at 100 cm SSD, the 50% contour has a central-axis depth as follows:

4 MV : 13.7 cm

5 MV : 14.5 cm

6 MV : 15.2 cm

The use of an incorrect beam energy can sometimes be deduced from observation of the dose variation across the field. For example:

- if the dose at the isocentre is higher than the dose at the 20 cm points, the beam energy is probably high;
- if the dose at the isocentre is lower than the dose at the 20 cm points, the beam energy is probably low.

4. X-RAY LEAKAGE RADIATION

4.1 INTRODUCTION

Unless the electron beam in the accelerator follows a nearly-central path throughout its passage from gun to target, there is a possibility that some interception of the beam will occur. This will give rise to an increase in X-ray leakage radiation; also, if a substantial collision is allowed to persist, damage could occur due to overheating. Normally it is only during adjustments to the beam controls, i.e. gun and centring systems, that any danger arises. Accordingly, after any such work, which includes replacing the gun or its filament, the procedure for checking the leakage radiation should be carried out, as next described.

4.2 MEASUREMENT OF X-RAY LEAKAGE RADIATION

The focus coil currents and centring currents 1R and 1T are set up in the factory, and adjusted if necessary during installation, to produce the highest dose-rate compatible with a prescribed level of leakage radiation. If focus currents or centring currents other than these original settings are subsequently used, the leakage radiation levels resulting from this use must be checked. If the leakage radiation levels are excessive, corrections must be made to the focus and centring coil currents.

A comprehensive check of the leakage radiation would require measurement of the leakage dose at any point in a plane circular surface of radius 1 metre centred on and perpendicular to the axis of the X-ray beam, at the normal treatment distance and outside the maximum useful beam area. At each point, the absorbed dose due to leakage radiation should not exceed 0.1% of the maximum absorbed dose at the point of intersection of the axis of the beam and the plane surface. Such a check would be tedious and, in practice, it is sufficient to check as follows:

(1) Set the gantry to 0°, so that the X-ray beam will be directed vertically down. Set the radiation head to 0° and the diaphragms in the radiation head for a field size of 10 cm x 10 cm.

(2) At the isocentre, position a large-volume ionisation chamber (e.g. 40 to 60 cm^3) fitted with a suitable build-up cap, and connect the chamber to a dosemeter. Establish a setting of dose (e.g. 100 units) such that levels of about 0.1% of this value can be measured on the dosemeter by range-switching. The dose measured at the isocentre shall be noted for use as the reference dose.

(3) Fully close the diaphragms in the radiation head. Set the large-volume ionisation chamber successively to the points at 45° intervals on a circle of 1 metre radius in a horizontal plane situated 1 metre from the target, as shown in Fig. 1(a), and measure the leakage radiation at each point. Check that the leakage dose does not anywhere exceed 0.1% of the reference dose measured at the isocentre in step (2). Repeat the measurements for circles of 75 cm and 50 cm radius.

(4) Rotate the gantry through 90° so that the X-ray beam will be directed horizontally. Set the large-volume ionisation chamber successively to the four points on a circle of 1 metre radius, and at the G50, G100 cm points, all in a horizontal plane situated 1 metre from the target, as shown in Fig. 1(b). Measure the leakage radiation at each point and check that the leakage dose does not exceed 0.1% of that measured at the isocentre, (or 0.2% for points G50, G100).

(5) If the leakage radiation measured at any point is significantly higher than specified, proceed as in 4.3.

4.3 CORRECTION OF EXCESSIVE X-RAY LEAKAGE RADIATION

The Focus currents will have been optimised in the factory and checked on installation. In particular, the Focus 1 current level will have been set to satisfy, as far as possible, the following two conditions simultaneously:

- High output dose-rate;
- Low level of leakage radiation.

Thus, normally it should not be necessary to change from these established levels of focus current, and the required corrections are then applied by adjustment of centring currents 1T and 1R only.

Proceed as follows:

(1) Position the large-volume ionisation chamber at the check point where the high leakage radiation was found. Set the associated dosemeter to indicate dose-rate.

(2) Switch-on the Linac with all servo-systems operating. Adjust the 1T centring current, in steps, by means of RV8 on PWB76-LL (see Chapter 9, Fig. 6) and, at each step, compare the leakage dose-rate indicated on the external dosemeter with the DOSE RATE reading displayed on the engineer's panel of the TCC.

(3) After checking the leakage dose-rate over a range of 1T centring currents, adjust RV8 for minimum leakage dose-rate without loss of useful beam output.

(4) Repeat the procedure in (2) and (3), but for 1R centring current, using RV9 on PWB76-LL (see Chapter 9, Fig. 6).

(5) After optimising the centring currents 1T and 1R for minimum leakage radiation, recheck the leakage radiation as in 4.2 above. If this is now acceptable, check X-ray field flatness and make adjustments if necessary.

* * * * *

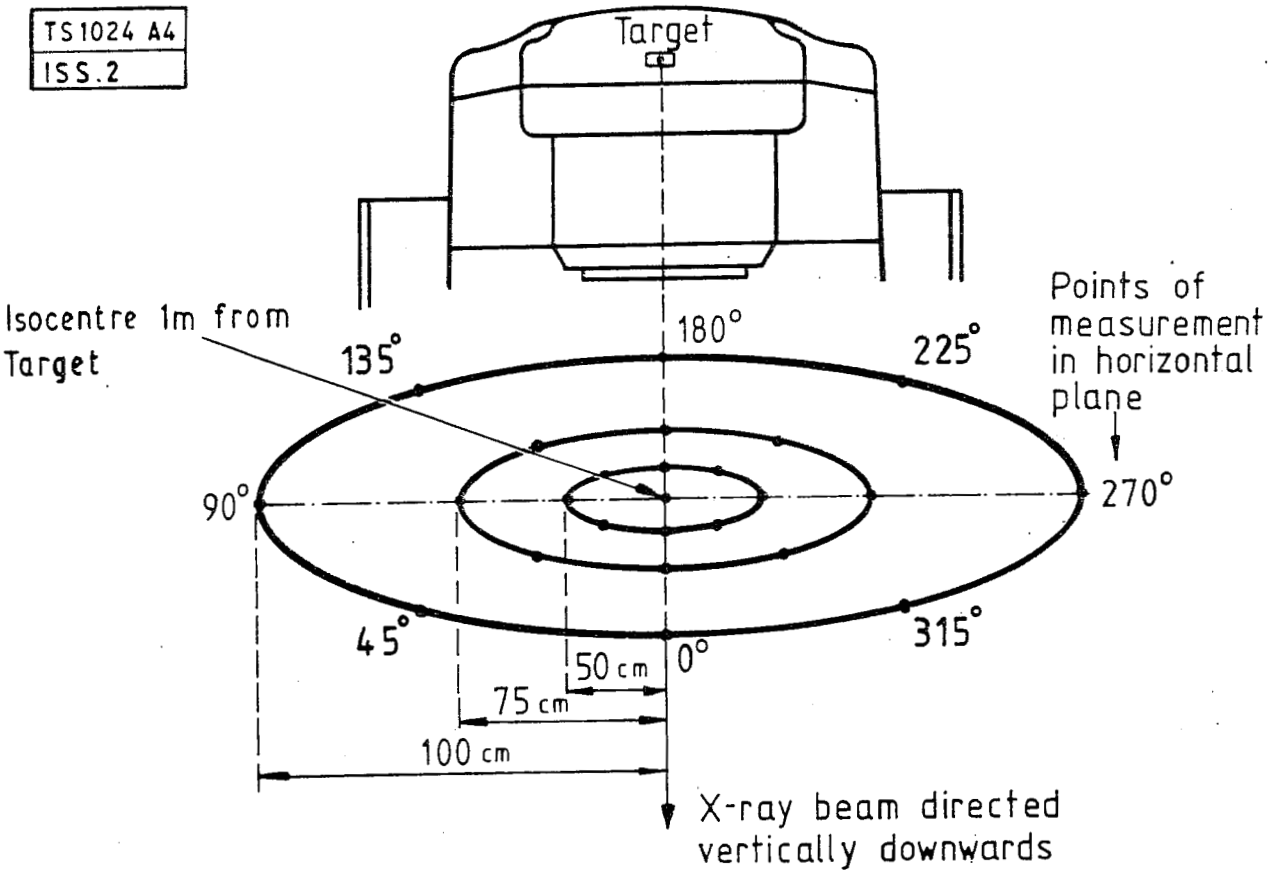

Figure 1: Leakage radiation check points with X-ray beam directed vertically downwards

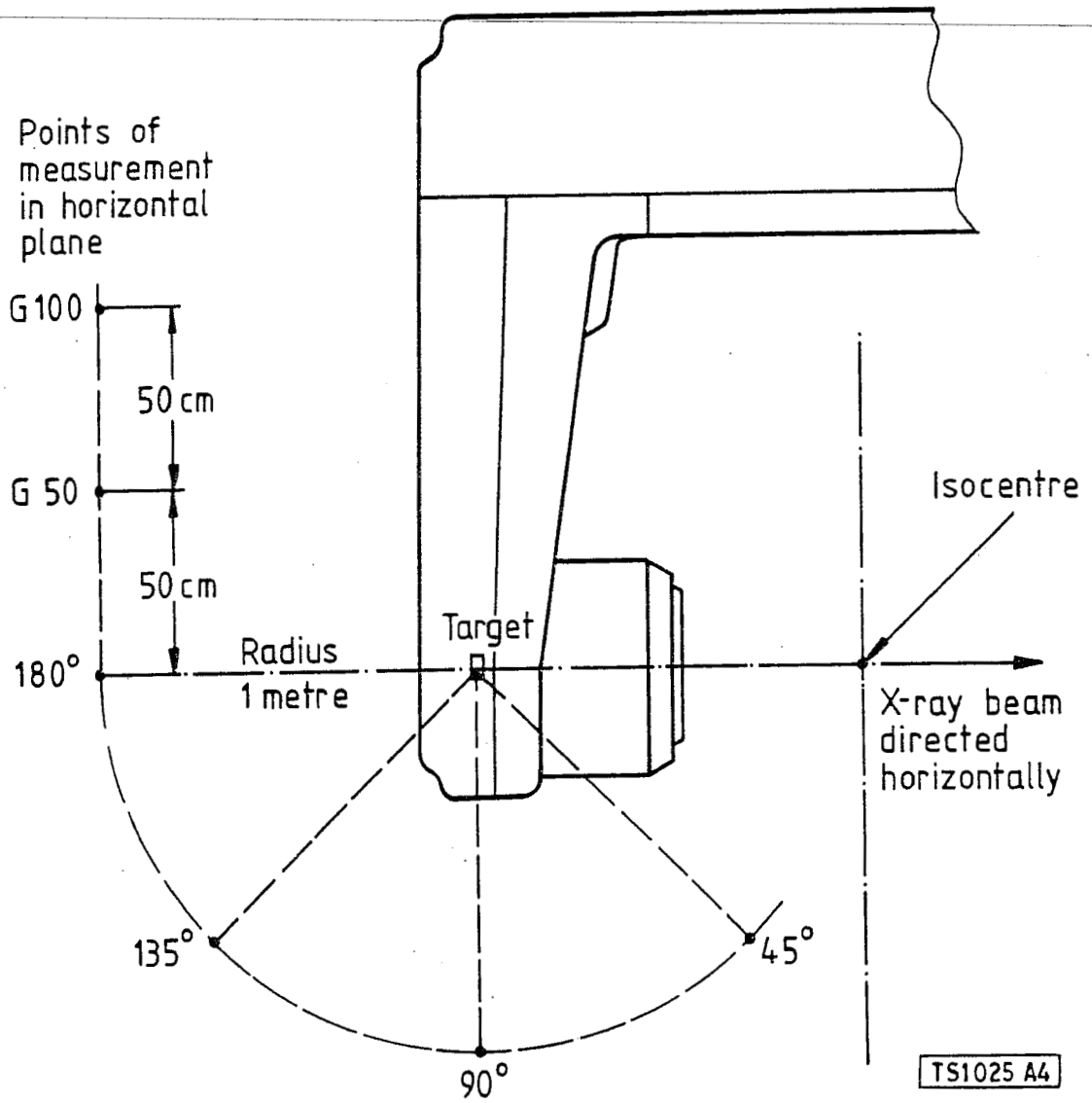

Figure 2: Leakage radiation check points with X-ray beam directed horizontally

Chapter 13: SUPPLEMENTARY INFORMATION

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Annexe A - Dose Integrator PWB 76-H/K C 4513 390 0594

Annexe A

DOSE INTEGRATOR PWB 76-H/K: C 4513 390 0594

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ILLUSTRATIONS

Block Diagram, Dose Integrator PWB 76-H/K: C 4513 390 0594 . . . . . AZ-1

1. FUNCTION

The two identical dose integrator boards, one for each dosimetry channel, perform the following common functions:

- The generation of one pulse per 1/125 MU delivered dose, derived from the ionisation chamber input, for use in the dosimetry logic boards.
- The generation of the PRF assert/inhibit signal, output to the PRF Generator, under certain conditions.
- The completion, under controlled conditions, of the 24 V a.c. interlock chain for the appropriate channel.
- The detection of +10 V, +/-15 V and -300 V supply faults with the resultant termination of treatment (de-energisation of RL-A).

In addition:

- Channel 1 (PWB 76-H) generates an analogue dose rate signal (negative) for use in the Moving Treatment Controller PWB 76-F, as part of the computation necessary for control of gantry rotational speed in the arc therapy mode.
- Channel 2 (PWB 76-K) provides an analogue dose rate level, output to the ADC PWB 76-MM, for conversion into signals suitable to drive (as the dose rate indication) the engineer's monitor display on the TCC.

2. CIRCUIT DESCRIPTION

AZ-1 shows the circuit in block diagram form. The circuit diagram is filed in Vol.3 of this manual (Annexe C to Vol.3 refers).

Each 2.5 microsecond radiation pulse produces a negative charge-flow to the positive plates of the multi-plate ionisation chamber (one plate is used for each channel). The capacitance of the coaxial cable connecting the ionisation chamber to the dose integrator board at Pin Hb, and the response time of the chamber, lengthen the pulse to about 50 - 100 microseconds.

The basis of the measurement system is the integration of the current pulses from the ionisation chamber. The integrator output voltage continuously ramps up to a calibration level and is then reset rapidly to zero in a sawtooth-like waveform. The calibration level is set so that one cycle of the sawtooth represents a delivered dose of 1 MU (i.e. one pulse at IC9-15). The sawtooth frequency is thus a measure of the dose rate, and the total accumulated dose is obtained (on the Dosimetry Logic board) by counting the cycles.

A tracking integrator is set to run to give pulses representing 1/250 MU (i.e. at IC9-6); but this is divided by 2 at IC6 to represent 1/125 MU pulses.

2.1 TRACKING INTEGRATOR

With TR7 off, current pulses from the ionisation chamber cause integrator capacitor C6 to charge up, and the integrator output voltage at TP1 rises steadily. This voltage is "tracked" by the output of 12-bit binary counter IC9 as follows:

The counter is driven by the output of a free-running oscillator (IC5-3 with external R-C). The 11 least significant bits (LSB) of the counter output are fed to D/A converter IC8.

IC8 employs an R-2R ladder network, its individual elements being selected by the bits of the counter output word. The ladder network therefore has an effective lumped resistance which represents the instantaneous value of the counter output word. This lumped resistance is connected in series with an internal "feedback" resistor to form a voltage divider. Connected across the voltage divider are:

- A negative calibration voltage at IC8-17.
- The dose integrator output (positive) at IC8-18.

The overall effect on the voltage divider output, i.e. the D/A converter output at IC8-1, is as follows:

- An increasing count drives the output negative.
- An increasing voltage input from the integrator drives the output positive.

Tracking is achieved by using the D/A converter output at IC8-1 to inhibit the operation of the oscillator whenever IC8-1 output just goes negative by the voltage divider action.

The following counter output bits have additional significance (Bit 1 = LSB):

Bit 3 (IC9-6): The dose integrator output in 1/250 MU pulses.

Bit 11 (IC9-15): When this bit goes high, an integrator/counter reset is initiated (1MU counted).

Bit 12 (IC9-1): This bit will only set under fault conditions, stopping the count. An overrun of 1MU maximum is allowed.

2.2 DOSE RATE OUTPUT

1/250 MU pulses from IC9-6 are fed to the clock input (Pin 11) of flip-flop IC6. Each pulse causes IC6 complementary outputs (Pins 12 and 13) to toggle. These outputs drive switches in IC3, thereby sending a fixed charge per

1/250 MU to low-pass filter circuit IC4. The average output from IC4 is fed to the moving treatment controller to determine the gantry speed during arc therapy, and to the ADC PWB (76-MM) via buffer IC7-5 to drive the dose-rate monitor display at the engineer's panel of the TCC.

2.3 DOSE COUNT OUTPUT

1/125 MU pulses from IC6-13 are coupled via optocoupler IC20 to edge connector Vb for transmission to the dosimetry logic board.

2.4 CALIBRATION VOLTAGE

Different calibration voltage levels are required to compensate for the effect of backscatter when the wedge and/or beam absorber are engaged. Calibration voltages are adjusted using potentiometers RV1 to RV10. The appropriate potentiometer output is then selected by multiplexer IC1 according to a four-bit ENERGY code from the Treatment Parameter PWB at IC1-10/11/13/14. IC1 output at IC1-1 is inverted at IC15-6.

2.5 RESET GENERATION

At the end of each count sequence, Bit 11 (IC9-15) of the counter output goes high, triggering a negative pulse from Pin 7 of retriggerable monostable IC 10. This pulse resets the counter. It also pulses TR7 to discharge integrator capacitor C6. As the reset period of 5 microseconds is very short compared with the integration time constant, the system effectively integrates continuously.

2.6 FAULT LATCH

IC12-3/4/11 form a latching circuit which protects against spurious resets occurring immediately after the integrator has been reset. The latch output at IC12-3 is fed to Pin 5 of monostable IC10 and has two stable states:

Low	Forced by the reset pulse from IC10. DISABLES MONOSTABLE IC10.
High	Forced by the high which appears on the output of comparator IC13-15 when C6 is fully discharged. ENABLES MONOSTABLE IC10.

In the absence of a reset pulse, the counter will continue to count until its MSB (IC9-1) sets. This bit is inverted at IC5-10, gating off the oscillator output to the counter at IC5-4, and stopping the count.

2.7 DOSIMETRY RESET

The RESET DOSIMETRY L signal at edge-connector Pin Na is derived from the dosimetry logic board and is set low by the microprocessor prior to treatment. This resets latch IC6 (IC6-1 low), resetting the dose integrator. When treatment commences, the RESET DOSIMETRY signal goes high and the HT ON signal (+24 V) at edge connector Pin 13b sets latch IC6, thereby removing the reset signal. This ensures that the dosimetry is active when HT is on.

2.8 COMPLETE SEQUENCE

The 1/125 MU pulses are counted on the dosimetry logic board, and when the prescribed dose has been delivered, the microprocessor orders the completion of the Channel 2 dose count. This results in edge-connector Pin Ma going high (COMPLETE SEQUENCE), thereby causing a simulated ionisation chamber signal to be applied to the dose integrator via opto-coupler IC14. When the Channel 2 dose count is complete, the microprocessor clears the COMPLETE SEQUENCE signal.

2.9 SUPPLIES FAULT DETECTOR

One pair of voltages derived from each of the +10 V, +/-15 V and -300 V supplies is fed to the inputs of four-channel comparator IC2. One voltage from each pair drives the positive input of one of the comparator channels, and the other drives the negative input of a different comparator channel. Each channel output switches from open-circuit to ground via an open-collector transistor when its input voltage differential goes negative. Input voltages are scaled so that in normal operation, the open-circuit output condition prevails. The failure (high or low) of one of the power supplies will drive one of the comparator channel outputs low. The comparator outputs are wire-OR'd together so that when one output goes low, the combined output is pulled low, signalling a supplies fault.

2.10 DOSIMETRY STATUS

Tri-state buffer IC16 interfaces Bits D0 and D1 of the DOSIMETRY STATUS byte to the microprocessor. Bit D0 is the MSB of the counter output (IC9-1) as transmitted via optocoupler IC17-6. This is the overrun check. If the dose integrator is not reset at 1 MU, the counter will overrun to allow a maximum of 1 extra MU to be delivered before this bit is asserted. Bit D1 is the output of the supplies fault detector circuit as transmitted via optocoupler IC17-7. Both bits will be low under 'no-fault' conditions.

2.11 INTERLOCK CIRCUITS

2.11.1 24 V a.c. Main Interlock

The +24 V supply for RLA is present at edge connector Pin 10b, but the relay can only become energised when the following conditions obtain:

(1) The INTERLOCK ENABLE signal at Pin 17b from the dosimetry logic board is high. This level is set in latch IC24 on the dosimetry logic board by a WRITE 16 from D7 of the databus.

(2) The signal ENERGISE RELAY (low) from the dosimetry logic board is present at Pin Pa.

(3) A supplies fault is not present. TR4 is therefore biased on by the output of the supplies fault detector circuit.

Thus TR3 conducts, supplying RLA with +24V to complete the 24 V a.c. main interlock chain for treatment via Pins Yb and 21b.

2.11.2 PRF Enable

The PRF ENABLE/INHIBIT signal to the PRF generator PWB is taken from Pin 6b of the Channel 1 dose integrator board. The signal is derived via TR6 on both Channel 1 and Channel 2 boards. The two boards are interconnected so that the two transistors TR6 are in series between the +15 V supply and a -15 V PRF ENABLE signal from the clock/calendar PWB (Pin Nb of PWB 76-K is connected to Pin Pb of PWB 76-N). To obtain the PRF ENABLE signal level of -15 V, both transistors must be conducting; if either transistor is cut off, the voltage at Pin 6b becomes more positive than -6 V, the PRF INHIBIT level.

Transistors TR6 are held conducting by a combination of:

(1) The energising current for RLA via optocoupler IC23 and TR4. (The optocoupler output transistor conducts, biasing off TR5.)

(2) The PRF ASSERT signal derived from the treatment timer board via IC11-3 and optocoupler IC25. (The optocoupler output transistor conducts, supplying base current to TR6).

3. MAINTENANCE INFORMATION

3.1 SUPPLIES FAULT DETECTOR - set RV12 for -300 V Monitor trip level, Ch.1 and 2

(1) On PWB-H, set the voltage on the wiper of RV12 to +2.5V with respect to 0V M/C at TP2.

(2) Repeat (1) for PWB-K.

(3) Select Option 5 Page 2 and check that removing the -300V supply at coax socket SK70-AA causes the seventh bits from the left in lines 4 and 5 to change from '0' to '1'.

(4) Replace the coax cable at SK70-AA.

3.2 ENGINEER'S MONITOR DOSE RATE DISPLAY - set zero Ch.2 RV13

With system powered up but no radiation, adjust RV13 on PWB 76-K (Channel 2) to set dose rate indication to zero.

3.3 TRACKING INTEGRATOR CIRCUIT - set calibration voltage levels

Due to the effect of backscatter, a different calibration is required for each combination of wedge filter and beam absorber. For each combination, the calibration procedure is the same, but is effected using a different potentiometer as follows:

Combination	Beam Absorber	Wedge	Cal. Pot.
A	Retracted/Absent	Out	RV1
B	Retracted/Absent	In Beam	RV9
C	Extended	Out	RV2
D	Extended	In Beam	RV10

First calibrate Channel 1 for each of the applicable combinations. The results obtained are then used as the standard against which Channel 2 is calibrated.3.3.1

3.3.1 Calibration of Channel 1 (PWB 76-H)

(1) PRF — Set to 300 pps (PRF selector to position 3).

(2) Wedge filter and beam absorber — Extend/retract according to combination (A,B,C or D - see table) under calibration.

(3) Thimble ionisation chamber — Place at a depth of 5 cm in the water phantom.

(4) Diaphragms — Adjust to give a field size of 10 cm x 10 cm.

(5) Standard dosemeter — Connect to the thimble ionisation and set instrument to measure integrated dose.

(6) Set up a test treatment, using the CONTROL T facility, selecting a start dose of 100 and adequate exposure time.

(7) Start the treatment and hold the START key depressed.

Immediately after treatment termination:

(8) Standard dosemeter — Read off, and, applying the correction factors for temperature, pressure, energy, etc., obtain the true dose at the isocentre.

(9) VDU — Read off the displayed dose 1 value.

(10) Cal. Pot. (see table) — Adjust as required to set the reading obtained in Step 9 to within 1% of the true dose obtained in Step 8.

(11) Repeat Steps 6,7,8 and 9 with a PRF of 150/180 pps set (PRF selector to position 2) and verify that the calibration is unaltered.

3.3.2 Calibration of Channel 2 (PWB 76-K)

Repeat Steps 1,2,6 and 7 of the Channel 1 calibration procedure for each applicable combination (A,B,C or D - see table).

Immediately after each treatment termination:

(1)	VDU	Read off the displayed dose 2 value and verify that it is within 1% of that displayed for dose 1.
(2)	Cal. Pot. (see table)	Adjust as required to obtain the accuracy called for in Step 1.

3.4 ENGINEER'S MONITOR DOSE RATE DISPLAY - set level Ch.2 RV11

(1)	Set up and start a test treatment.	
(2)	VDU	Monitor the dose rate displayed.
(3)	Eng. mon. display	Monitor the dose rate displayed.
(4)	RV11 (PWB 76-K Ch.2)	Adjust as required to correct any error in the engineer's monitor display dose rate readout with respect to the VDU dose rate readout.